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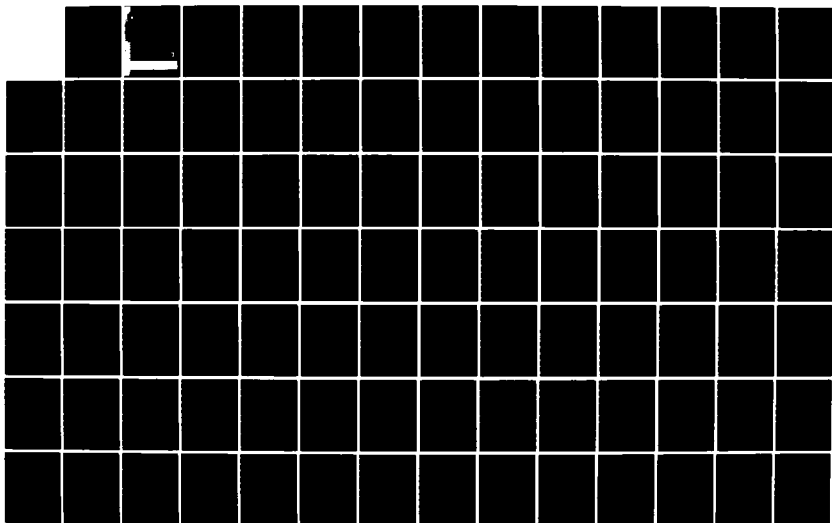
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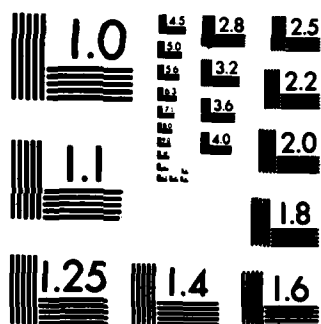
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Human Engineer's Guide to Auditory Displays, Vol. 1:

ELEMENTS OF PERCEPTION AND MEMORY  
AFFECTING AUDITORY DISPLAYS

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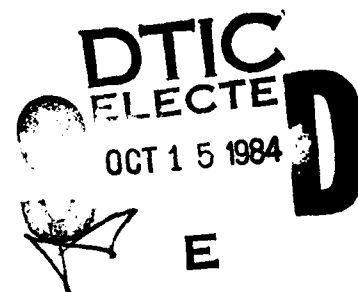
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ABSTRACT

ELEMENTS OF PERCEPTION AND MEMORY  
AFFECTING AUDITORY DISPLAYS

This work reviews the areas of auditory attention, recognition, memory and auditory perception of patterns, pitch, and loudness. The review was written from the perspective of human engineering and focuses primarily on auditory processing of information contained in acoustic signals. The impetus for this effort was to establish a data base to be utilized in the design and evaluation of acoustic displays. The organization of the report is in the form of questions and answers. The questions are numbered and listed as an index in Appendix I to provide access to appropriate sections of the text. The question index also contains citations of the scientific literature on which was based the answers to each question. There are ninety-four questions and answers, and more than two hundred citations contained in the list of references given in Appendix II. This is one of two companion volumes, the other of which reviews the literature in the areas of auditory detection, discrimination (including reaction time to acoustic stimuli) and binaural processing.

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ELEMENTS OF PERCEPTION AND MEMORY  
AFFECTING AUDITORY DISPLAYS

This work is one of two in-depth reviews of the scientific literature pertaining to the major areas of auditory processing in humans. The areas covered in this report are auditory attention, recognition, memory, and the perception of auditory patterns, pitch and loudness. More than two hundred scientific reports, reviews, and books provided the information substrate on which this report is based. These documents were selected from the general literature available in the above areas on the bases of recency and relevance to the present objective, i.e., achieving an understanding of the processing of auditory signals that is applicable to design and evaluation of acoustic displays.

As a means of providing the reader with an application-oriented guide to the information presented herein, each unit of information is organized in the form of an answer to a specific question, where the questions themselves were formulated from the perspective of human engineering. There are ninety-four such questions of varying degrees of specificity with answers of correspondingly variable lengths and detail. The particular literature on which each answer is based is cited in standard scientific style and listed in full reference format in Appendix II. Each question is numbered throughout the text. These numbers correspond to a listing of the questions in Appendix I which may be used as an index to facilitate the location of questions of interest within the text. The question list in Appendix I also contains, for

each question, citations of the pertinent literature to permit direct referral to the list of references in Appendix II.

The subject of primary focus is auditory processing of non-speech acoustic signals. However, in order to adequately treat certain areas (auditory attention, recognition, and memory), it was necessary to include studies involving speech signals. This literature was reviewed, wherever possible, from the perspective of information processing of acoustic signals in general rather than processing peculiar to the speech domain.

Although the implications for acoustic displays of much of the material discussed will be obvious, the reader is cautioned against drawing "hard and fast" conclusions for specific applications. Such conclusions may be isolated, out of context, and consequently inappropriate. A general model of auditory processing needs to be developed taking into account the information contained in this report, as well as that reviewed in its companion volume covering the areas of auditory detection, discrimination (including reaction times to acoustic stimuli), and binaural processing.<sup>1</sup> Such a model would integrate this information and provide a means of establishing boundary conditions on the applicability of the conclusions drawn from it.

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<sup>1</sup>Mulligan, B. E., Goodman, L. S., McBride, D. K., Mitchell, T. M., Crosby, T. N., Gleisner, D. P., Stewart, K. D., and Hitchcock, L., Human Engineer's Guide to Auditory Displays, Vol. 2: Elements of Signal Reception and Resolution Affecting Auditory Displays, September 1982.

1. Can listeners identify categories of nonspeech sounds?

Common experience indicates that listeners can categorically identify nonspeech sounds. For example, a chord is easily recognized wherever it is played on the musical scale. Scientific interest in the identifiability of categories of nonspeech sounds has been extended to include a variety of sound types. The onsets of "noise-buzz" sounds provide a basis for categorical identification (Miller, Weir, Pastore, Kelley and Dooling, 1976). Likewise, the onsets of two-component tones enable identification of categories (Pisone, 1977), as do musical intervals (Locke and Kellar, 1973) and patterns of intensity variations and sinusoidal frequencies (Pastore, 1976). In an interesting series of experiments, Cutting (1977) and Cutting and Rosner (1974, 1976) varied rise times of sawtooth waves and found that short rise time (0-30 msec) were categorized differently than longer rise times (50-80 msec). The former were identified as "plucked strings" while the latter were identified as "bowed strings." Categorical perception of nonspeech sounds is comparable with that for speech sounds (e.g., Studdert-Kennedy, Liberman, Harris, and Cooper, 1970; Mattingly, Liberman, Syrdal and Halwes, 1971). It should be noted that sounds assigned to the same category are relatively indistinguishable.

Incidentally, the argument that categorical perception of sound is not peculiar to speech is given added support by the finding that it may occur in non-humans (Kuhl and Miller, 1975; Morse and Snowden, 1975), though the matter is not yet settled (Sinnott, Beecher, Moody and Stebbins, 1976; Waters and Wilson, 1976).

2. Must categorical identification of sounds be learned, or is this innate?

It appears that categorical identification of sounds is an innate capability. Eimas, Siquiland, Jusczyk, and Vigorito (1971) found that infants one month old discriminated speech sounds (stop consonants) in a manner identical to adults. With respect to nonspeech sounds, it has been found that infants discriminate between plucked and bowed sounds, just as do adults (Jusczyk, Rosner, Cutting, Foard and Smith, 1977). It has not yet been established whether infants categorize sounds on the basis of tonal mode (chords), but it would seem reasonable to suppose that they do since Plomp and Levelt (1965) found that tonal consonants and dissonance was determined by the auditory ("critical band") filter, and since Fletcher (1940), Zwicker et al. (1957), Plomp and Bouman (1959), Mulligan and Elrod (1970), Patterson (1971, 1974, 1976), and others have shown that the filter passband in humans is a characteristic of the auditory system.

3. Does memory for auditory inputs exist at an initial, sensory ("precategorical") level, or is it limited to the more abstract, highly processed ("postcategorical") levels of short-term and long-term storage?

This question does not appear as yet to have been unambiguously resolved for either vision or audition (Holding, 1975). However, Crowder (1978) has argued convincingly that the concept of sensory memory cannot be rejected on the basis of existing evidence. Indeed, Crowder does much to establish both the conceptual and empirical necessity of this concept -- "iconic memory" in vision and "echoic memory" in audition. According to

Crowder, sensory memory holds the input in raw, unprocessed form for a duration of time that may outlast the stimulus exposure thereby increasing the likelihood that the "trace" will be available for sufficient higher-order processing to achieve "categorization." For example, if a stream of auditory information were presented in temporally isolated units, it would be heard as a succession of discrete inputs if the time separation between adjacent units exceeded the holding time in echoic memory. Otherwise, it would be heard as a continuous input. Presumably, it is the sensory memory trace that bridges the time-gap (however, see questions 71 and 92). Several studies with segmented speech and dichotic pulse trains (Huggins, 1975) indicate that the time-gap for audition may lie in the range between 50 and 200 msec. However, different input and task demands may result in much longer critical times, e.g., two or three seconds (Kubovy and Howard, 1976).

By comparison, the longer-term, higher-order processing that is presumably involved in at least some aspects of pitch recognition (e.g., see Deutsch, 1975a; Deutsch and Feroe, 1975) would seem to qualify as a candidate for post-categorical memory. Apparently, this system is organized along two dimensions, "tone-height" and "tone-chroma," and may involve processing akin to lateral inhibition (however, see question 9). These characteristics of the pitch system were deduced from a series of experimental outcomes obtained by Deutsch (for an overview of this work see Deutsch, 1978). Pitch recognition performance was found to be a function of the relative frequency and temporal positions of serially presented tones. In the interval between two test tones a sequence of six tones was introduced. Errors in pitch recognition were found to depend on

the frequency relationships among the tones, as well as their serial positions (also see question 11). Octave transpositions produced effects in keeping with frequency ratios, with the exception that higher octave tones produced more interference than lower octave tones. Deutsch and Feroe (1975) hypothesized a pitch memory array organized on a log-frequency scale the elements of which are activated by tones of appropriate pitch position. This would constitute the basis for classification of this system as post-categorical. However, the involvement of lateral inhibitory processing would seem to be in the realm of pre-categorical sensory memory, if Crowder's distinction is applicable in this case. Furthermore, it seems unlikely that Deutsch's categorical memory structure would necessarily depend upon learning.

4. Is memory better for absolute values of acoustic inputs than it is for relationships among input values?

It appears to be well established that memory persists longer for the relationships among the values of acoustic inputs (Deutsch, 1978). For example, not only are harmonic sequences, or melodies, recognized after being transposed to a new key, the original key may not be recognized sometime after the exposure to it (Deutsch, 1969; Attneave and Olson, 1971). Hence, the relationships among pitches (melodies) are retained, but usually not the absolute pitches. As Ward (1970) pointed out, "... transposition is the rule, not the exception." The exception seems to be the rare individual capable of absolute pitch identification. In general, as Pollack (1972) has shown, memory for waveform usually does not

persist. The extent to which it does persist is subject to direct disruption if, after initial exposure to the pitch of a test tone, a series of tones differing in pitch are presented before the second test tone (Deutsch, 1970, 1972b, 1973, 1975a). Errors in identifying the correct pitch of the second test tone was shown to be a function of the log-frequency difference between the first test tone and one (Deutsch, 1972b) or two (Deutsch, 1973) of the interpolated tones. However, if one of the interpolated tones matches the test tone an improvement in performance was found to occur (Deutsch, 1975b). Consistent with the finding that it is the frequency relationship between test tones and interpolated tones which results in either the facilitation or disruption, spoken numbers interpolated between test tones resulted in relatively slight disruption (Deutsch, 1970). In any case, memory for pitch is weak (Pollack, 1964).

5. What global cues for recognition and memory are available in complex tonal sequences?

In complex tonal sequences such as music, global cues include the overall pitch range, the average size of ascending and descending intervals (as well as the relative proportions of such intervals), the sequence of directions of pitch change, etc. (Deutsch, 1978). These are characteristics that form the "contours" of melodies. Some may be distorted and the remaining cues still permit recognition. For example, White (1960) altered the intervals of melodies and obtained recognition on the basis of sequential directions of pitch change. Recognition

performance was least affected when only the absolute sizes of intervals was changed. Altering the relative interval sizes affected performance to a greater extent. Similar results involving melodic transposition with, and without, distortions in interval sizes were obtained by Dowling and Fujitani (1971). Even the rhythmic information alone in a monotone may account for some melodic recognition, as shown by White (1960) and Deutsch (1972a).

6. What factors contribute to the formation of perceptual configurations of sounds?

The factors that are responsible for grouping of acoustic components into perceptually coherent configurations (or which exclude certain components from coherent configurations) are frequency disparity (Miller and Heise, 1950; Heise and Miller, 1951; Bregman and Campbell, 1971), rate of presentation of frequency-disparate components (Van Noorden, 1975), timbre disparity (Deutsch, 1978), unidirectional continuance of patterned change (Divenyi and Hirsh, 1974, 1975), and rhythm (Fraisse, 1978; Perkins, 1974; Handel, 1973j,; Restle, 1972).

Sequences of tones will be heard as a coherent "stream" (Bregman and Campbell, 1971) if the frequency disparity of the tonal components is not too great. Miller and Heise (1950) found that, if tones did not differ in frequency by more than about 15%, they would be heard as a unitary pattern. Frequency differences greater than 15% were not heard as a connected series, but rather as unrelated tone segments. For the case of

frequency disparities much greater than 15%, Heise and Miller (1951) reported that the disparate tone was perceptually isolated from the pattern and seemed to originate from a separate sound source. In these studies, tones were presented at a rate of  $10 \text{ sec}^{-1}$ .

The effect of rate of tonal presentation on perceptual grouping was investigated by Van Noorden (1975). In this study observers listened for either one coherent tonal sequence, or two. If they listened for one pattern, grouping was achieved with larger values of frequency separation at slow rates of presentation (about  $6 \text{ sec}^{-1}$ ), i.e., the slower the rate the larger the frequency separation. However, if observers listened for two separate patterns, presentation rate had little effect.

Differences in timbre (e.g., spectral composition of the sounds peculiar to a musical instrument) also provide a basis for perceptual grouping. Sounds generated by the same kind of instrument are heard together. If two instruments differ noticeably in timbre, they will be heard separately. Deutsch (1978) discusses this in terms of figureground. For example, the sound of a flute, combined with the sounds of several violins, will be heard separately as figure against ground. The order in a sequence of sounds may not be heard if the components in the sequence differ in timbre (Warren and Obusek, 1972). In this case the sounds will be perceptually grouped into different streams on the basis of timbre and the overall sequential order will be missed. Garner (1974) suggests that different processes operate at fast and slow rates. Presumably, at fast rates immediate perceptual representation of serial order occurs, whereas,

at slow rates perception of the relations among successive events depend on memory and Gestalt operations.

Continuation of a unidirectional patterned change in a sequence of tones (e.g., each successive tone increases in pitch, or vise versa) may be responsible for perceptual grouping. For example, Divenyi and Hirsh (1974, 1975) found that the identifiability of tonal temporal order was enhanced if the progression of pitch changes was unidirectional. Van Noorden (1975) found that coherence of three-tone sequences could be achieved at higher rates of presentation if pitch changes were unidirectional rather than bidirectional.

Perceptual grouping of tonal sequences may also depend on rhythm, or temporal organization of tonal components. For example, listeners will group a succession of sounds into rhythmic units where each unit contains an accented component followed by several unaccented components (Handel, 1973, 1974; Martin, 1972). The optimal rate of presentation for this kind of organization is about  $3 \text{ sec}^{-1}$ . The importance of accents in achieving rhythmic organization was also demonstrated by Perkins (1974). Deutsch (1978) noted that accents are effective because they differ from other components in the sequence along some attention-getting dimension (pitch, loudness, duration, or timbre). An additional variable that contributes to the perception of rhythmic organization is temporal separation of the tonal components (Handel, 1973; Restle, 1972).

7. If a repeating, rapid sequence of discrete tones is presented monaurally to a listener, what characteristics of these tones will determine the perceptual grouping of tonal components that is necessary for pattern (order and temporal spacing) recognition?

It appears that the primary characteristics of tones that determine perceptual grouping are spectral "similarity" or frequency separation of the tones, and speed of the tonal sequence. In a repeating six-tone sequence, if three of the tones are low frequency and three are in a higher frequency region, tones will group perceptually into two simultaneous "streams." Patterns of tonal order and temporal spacing are heard only within the streams. No pattern will be formed of components across streams. Listeners can identify the separate streams (Bregman and Dannenbring, 1973), identify patterns only within streams, and label the order of tones only within streams (Bregman and Campbell, 1971). Listeners perceive the components of the two streams as overlapping in time, even though they don't (Dannenbring and Bregman, 1976). Rhythmic patterns also are heard only among the components within a stream (Bregman, 1978b).

As the speed of the tonal sequence increases (tonal duration decreases), the frequency separation of tones that group into streams narrows (Van Noorden, 1975; Bregman, 1978a). As the number of tones in a temporally coherent series (unbroken by time-gaps that break the rhythm) increases, grouping into streams will occur at slower speeds (Bregman, 1978a).

The temporal structure of sequential patterns contributes to perceptual organization, reduces search time for event recognition, distinguishes salient elements from background, defines the relevant class of stimuli to be monitored, and reduces information load. Grouping is thus an efficient and load reducing way of processing sequential information (Bregman, 1978a).

Apparently, grouping into perceptual streams on the basis of tonal frequency occurs since, under natural conditions, this would be indicative of different sources of the sounds--high sounds originating from one source and low sounds from another. If frequency glides connect the sequential components of the sequence, the tendency to group is reduced (Bregman and Dannenbring, 1973, 1977).

Distracting tones can be eliminated from interfering in patterns by adding tones that group with them and cause a separate stream to be formed stripping the distractive tones away from the tones forming the pattern of interest (Bregman and Rudnicky, 1975). In addition to spectral similarity and speed of sequential tones, the synchronization of onsets and offsets of tones may serve as a basis for grouping (Bregman and Pinker, 1978) of sufficient strength to compete with other organizational tendencies. Set has also been shown to influence "stream" formation or perceptual organization (Van Noorden, 1975).

8. What are the structural components from which auditory patterns are formed?

Auditory patterns may be produced by simultaneously sounding acoustic components, by sequential sounding components, or by sequential progressions of successive simultaneous arrays. The pattern inherent in the frequency relationships of a musical chord, for example, may be sounded either simultaneously or sequentially, or as a temporal progression of chord changes.

In order for an auditory pattern to be formed, some invariant feature must be present in the acoustic array. The tonal relations in a chord constitute such an invariant feature--a pitch pattern--which is preserved after octave transposition even though the absolute pitches of the tonal components are different. The temporal grouping of successively presented tones also constitutes an invariant feature--rhythm--which is preserved after a time transformation that alters absolute durations throughout the sequence, but not relative temporal relations.

With the exception of patterns composed of simultaneously sounding elements (a composite of loudnesses, pitches, and/or timbres), auditory patterns are based on sequential invariants. In order for a sequential pattern to be identified, the relations among repeated components--or segments--must be recognized. According to Deutsch (1978), the relations that are identifiable in sequential auditory patterns include (1) tone chroma, (2) tone intervals, (3) chords, (4) overall pitch range traversed, (5) average size and relative proportion of ascending and descending intervals, (6) sequential directions of pitch change, and (7) rhythm.

Each type of relation may be important for recognition and recall of auditory patterns. Relations 4 through 6 form the perceptual contours of complex melodic sequences.

Although the above relations among repeated components and segments appear to be necessary for perception of auditory patterns, they may not be sufficient. In order that the pattern present in a temporal string of tones be perceived, presumably it is also necessary that the tones form a configuration, that is, that they be grouped together perceptually. For example, if the tonal components in a sequence are separated into two frequency regions, they will be heard as two simultaneous "streams" (Bregman, 1978a) rather than as one. Consequently, if the pattern of interest depends on relations among all the tones in the sequence, it appears that the pattern would be lost. It seems possible in this case that each of the two configurations might contain its own pattern if such were present in the relations among the two sets of sequential components. There is also the possibility that a more abstract pattern might exist between the two configurations. So far as we know, this has not been investigated.

The factors that contribute to perceptual grouping of components and auditory sequences include (1) frequency disparity, (2) rate of presentation of frequency-disparate components, (3) timbre disparity, (4) unidirectional continuance, and (5) periodic accents and durations of and between components.

A mathematical formulation of rules that describe the structural relations found in complex auditory patterns was provided by Jones (1974). Three structural levels are distinguished--nominal, ordinal, and interval. For example, a nominal structure would be produced by a periodic accent applied to an otherwise indistinguishable sequence of tonal components as indicated by the letter sequence auu/auu/auu. Ordinal structure is descriptive of contour, e.g., an ascending and descending pitch sequence symbolized by ++--++--. Interval structure is descriptive of melodic compositions such as that found in a sequence of whole tones and symbolized by +1, +3, -1, -2, +1, -1. For each of these structural classes, Jones presents a mathematical statement of the rule that governs transposition. In a recent review, Jones (1978) discusses the problem of structural descriptions of complex auditory patterns, and the various approaches taken toward its solution.

9. What physical dimensions of tonal inputs influence pitch perception?

Variations in tonal pitch are largely accounted for by tonal frequency. However, tone duration and, to a lesser extent, tone intensity may influence pitch judgements. The relationship of pitch (in mels) to frequency was originally determined by the method of fractionation (Stevens, Volkman, and Newman, 1937), and later by the methods of fractionation and equisection (Stevens and Volkman, 1940). The mel is defined such that the pitch of a 1000 Hz tone 40 dB above threshold is 1000 mels. The function relating mels to log-frequency positively accelerates as frequency increases up to about 1 kHz at which point it

becomes approximately linear and continues so up to about 5 or 6 kHz. The function accelerates negatively as frequency increases above this point. Pitch in mels increases ten-fold in the frequency ranges 25 Hz to 1 kHz, 1 to 3 kHz, and 3 to 9 kHz. It should be noted that the mel scale for pitch is not equivalent to the musical pitch scale which is a logarithmic scale of frequency.

The duration of tonal input has been shown to affect pitch only if duration is less than about 25 msec (Doughty and Garner, 1948). Tones of shorter duration were found to be of lower pitch. Pitch remained steady for durations greater than 25 msec.

The influence of intensity on pitch has been shown to be a minor one. Except possibly at low frequencies (below 100 Hz), pitch appears to be nearly independent of intensity (Cohen, 1961; Small and Campbell, 1961). There is, however, some indication that pitch may increase slightly at high intensities (Ward, 1970).

10. What basic features of tones are responsible for recognition of pitch combinations?

The three basic features of tones upon which recognition of pitch combinations depends are tone chroma, tonal intervals, and chords. These features are not exclusive entities, but derive from the frequency relations that exist among a set of tones. The relative position of a tone within the octave is known as its chroma, where the octave is

physically defined as a frequency ratio of 2:1. Tones that occupy the same relative position within different octaves are judged to be perceptually equivalent (Bachem, 1954) and result in stimulus generalization (Humphreys, 1939; Blackwell and Schlosberg, 1943). However, it should be noted that the perceptual octave is slightly larger than the physical octave, that is, subjects set the octave frequency ratio at values exceeding 2:1 and the magnitude of this over estimation ("octave stretch") increases at higher frequencies (Ward, 1954). The implication of these findings is that the selection of pitch of tonal signals should be based on both tonal frequency and octave position.

The frequency intervals separating simultaneously sounded tones may also result in perceptual equivalence. The frequency interval between any two tones will be heard as equivalent if the ratio of the tonal frequencies is the same, that is, if  $F_1/F_2 = F_3/F_4$ , then  $F_2 - F_1 = F_4 - F_3$  (Attneave and Olson, 1971). Incidentally, the frequency ratio 18:17 (the semitone) represents the smallest unit of the musical scale in Western culture.

In the case of simultaneous intervals (also chords), an interval of n semitones is perceptually similar to an interval of 12-n semitones (Plomp, Wagenaar, and Mimpen, 1973). This is known as the "inversion" phenomenon in music. Inverted intervals have been found to be confused (perceptually equivalent) with their non-inverted counterparts (Deutsch and Roll, 1974). Furthermore, musical intervals may be identified categorically (Burns and Ward, 1973; Siegel and Sopo, 1975).

The frequency ratios of three or more tones sounded either simultaneously or sequentially may form a chord. This is another instance of perceptual equivalence, that is, any three or more tones that form the same ratios are heard as the same chord. As Deutsch (1969) has pointed out, the perception of chords is not simply due to identical component frequency intervals, but rather is the result of an abstraction process that derives pitch relationships from tonal combinations. In the chord, then, it is the pitch relationship that is identified and named rather than the individual pitches of the component tones.

The importance of categorical perception of tonal intervals, chords, and chroma seems to be that this permits recognition of repeated elements in tonal sequences (Deutsch, 1978). Indeed, this would appear to be the most elemental basis available for recognition of tonal patterns.

11. Is recognition of the pitch category ("high" or "low") assigned to tones affected by the temporal proximity of other sounds?

Present research indicates that the answer to this question is yes. The percent correct categorizations of brief tones as being of "high" or "low" pitch increases as the time between offset of the test tone and onset of the "masker" sound (backward recognition masking) increases. At short intervals (20-60 msec), pitch categorization is little better than chance. At long intervals (greater than about 240 msec), performance reaches asymptotic levels comparable with that obtained in the absence of any masker (Massaro, 1972; Hawkins and Presson, 1977). If the test tone

is presented at one ear and the masker tone at the contralateral ear, or binaurally, relatively little recognition masking occurs even at very short (30 msec) intervals, provided the masker pitch is known to the listener (Hawkins and Presson, 1977).

Apparently, listeners cannot block the masker if its pitch is unknown or uncertain, even if the masker is presented to the opposite ear. Essentially, the same result was obtained by Massaro (1975), except in this case, the pitch uncertainty was attributable to the test tone and not to the masker which was of fixed frequency. Oddly enough, under monaural conditions, if the pitch of masker and test tone are close but known by the listener (no uncertainty), relatively little interference is produced by the masker. Evidently recognition masking is very different than backward masking in auditory signal detection. By contrast, insignificant effects of pitch uncertainty were obtained using a forward masking paradigm (Massaro, Cohen, and Idson, 1976).

12. Will recognition of the pitch of a target tone embedded in a series of tones of constant pitch be affected by the rate of tone presentation?

It appears that pitch recognition of embedded target tones does vary as a function of the rate of tone presentation. According to Massaro (1976), as the rate of presentation of series of 20-msec tones (800 Hz) decreased from 20 to 3.5 tones per second, there was an increase in correct recognition of the pitch of a target tone as "higher" or "lower" than the tone series pitch. The improvement in performance was approximately 20%.

essentially, the same result was obtained whether the tones were presented to one ear or switched between the ears. This suggests that backward recognition masking may operate in closely spaced tonal sequences. It also illustrates that, at slow rates of presentation, a tonal series may serve as a pitch reference against which pitch increases or decreases may be accurately recognized and, hence, provide a basis for encoding target information (also see question 93).

13. Under what conditions may pitch shifts occur?

Shifts in the pitch of a tonal signal of fixed frequency may be induced by previous stimulation as in auditory adaptation or fatigue, or by simultaneous stimulation as in masking. Using an adaptation procedure, Christman and Williams (1963) found that exposure to an adapting tone higher in frequency than the test signal (by 25 Hz) resulted in a pitch reduction of the subsequently presented test signal. The converse effect was obtained when the adapting tone was of a lower frequency. The time-course of the pitch shift was consistent with that typical of auditory fatigue (Mulligan and Adams, 1968). Shifts in pitch away from the frequency region of exposure have been obtained under conditions of auditory fatigue (Ward, 1963).

In the case of simultaneous masking of tones by narrow-band noise, tones just above the frequency region of the noise are shifted up in pitch while the opposite effect occurs for tones located just below the noise (Egan and Meyer, 1950; Webster and Schubert, 1954). If a "notch" has been

filtered out of a wide-band noise, the pitch of tones above and below the notch will be shifted toward the notch center (Webster et al., 1952).

It should also be mentioned in this context that a tone of a given frequency may not be of the same pitch in both ears of a listener. This condition is known as diplacusis, and it may occur in individuals with normal sensitivity functions. If pitch disparity between the ears is not too great, under binaural conditions listeners will tend to report a single pitch that is midway between the two pitches that would be obtained monaurally. See Ward (1970) for a discussion of this literature.

14. How can the illusion of an endlessly increased pitch be created with a limited number of tones?

Compose a number of tonal sets (say, two) where each set consists of several tones separated from the other set by one octave (same musical notes in each set). The notes in the two sets should form a series of notes (parallel scales) that increment in semitone steps. If the octave pairs in these tonal sets are presented in an ascending order at about  $1 \text{ sec}^{-1}$ , the listener will hear the sequence as increasing in pitch constantly. The listener will not hear the sequence recycle to the beginning tonal set if the notes in the lower octave gradually increase in loudness while those in the upper octave successively decrease. Pitch will appear to increase as long as the sets of tones are presented in order at a constant rate and the upper notes are made to become progressively weaker relative to the lower notes which become more

prominent toward the end of the cycle. The result of this balancing of prominence given to the upper and lower sets is that the pitch at the end of a cycle is precisely that at which it began. Thus, repeating the cycle creates the illusion of continuously increasing pitch (Shepard, 1964).

15. Do attentional shifts alter pitch and loudness difference thresholds?

Research by Ingham (1957) indicates that the answer to this question is no. Ingham found that the difference limen for neither pitch nor loudness was altered by changes in attention away from, or to, the ear in which the target signal was presented. This result is somewhat surprising. Common sense leads us to expect that the difference limen at one ear would be increased if attention were focused upon events at the opposite ear. However, Ingham's results are consistent with later findings by Moray (1970 a,b). These studies, in line with other investigations of auditory shadowing, have typically found that, although the content of attentionally rejected messages cannot be reported by listeners, the overall physical characteristics of rejected messages can be reported. Pitch and loudness, of course, are perceptual representations of the physical characteristics of sound and, thus, would not be subject to attentional rejection. Such interactions as this between auditory attention and basic auditory discrimination processes seem to have motivated relatively little experimental research. In light of this inadequacy, the findings of Ingham must be regarded as tentative. A pertinent report dealing with the influence of attentional processes upon human psychoacoustics was provided by Herman (1965).

## 16. What physical dimensions of sounds influence loudness perception?

Perhaps the one statement about loudness on which all psychophysicists would agree is that the loudness of sounds increases as a function of intensity. The form of this relationship, however, depends on how loudness is measured. The most widely accepted scale for loudness is Stevens' (1936, 1955) sone scale (adopted by the International Standards Organization). Unit loudness, one sone, is defined as the loudness of a 1 kHz tone at 40 dB above absolute threshold. The function relating loudness in sones of a 1 kHz tone to sound pressure level in decibels (plotted on log-lot coordinates) is negatively accelerating, becoming approximately linear above about 30 dB. For example, a 1 kHz tone has a loudness of 1 sone at 40 dB (relative to threshold), 2 sones at 50 dB, 3 sones at 60 dB, and so on up to 256 sones at 120 dB (Scharf and Fishken, 1970). The rate at which loudness grows with increases in intensity depends on tone frequency (Stevens and Davis, 1938, p. 118), the slope of the loudness function becoming larger as frequency moves away from the 1 kHz region in either direction. On the basis of free-field data from Fletcher and Munson (1933), Stevens and Davis (1938, p. 124) constructed "equal-loudness contours" which show the dependence of loudness on both frequency and intensity. These contours are plotted with loudness level in phones (defined as the intensity of a 1 kHz tone in dB relative to a reference pressure of  $20 \mu\text{N/m}^2$ ) as the parameter. The contour for 40 phones (1 sone), for example, traces the variations in intensity level (in dB) that are necessary to match a constant loudness as frequency changes. The family of contours are not flat across frequency, especially those for low and moderate levels of loudness. Generally, as tone frequency

increases toward 1 kHz, the intensity required to maintain constant loudness drops, and then rises again as frequency increases beyond 1 or 2 kHz. The lower boundary on these contours is the absolute threshold function of Sivian and White (1933).

In the course of their investigation of loudness matching, Fletcher and Munson (1933) found that the loudness of tones heard binaurally exceeded that of tones heard monaurally even though the input levels were the same. This binaural summation of loudness has since been studied for both noise and tones (Reynolds and Stevens, 1960; Scharf and Fishken, 1970, Hellman and Zwislocki, 1963) employing a variety of experimental techniques. Fletcher and Munson (1933) had suggested that binaural summation results in loudness that is twice as great as that heard monaurally. Although Reynolds and Stevens (1960) found this 2:1 ratio only at one level (90 dB) for bands of noise, Hellman and Zwislocki (1963) obtained results for tonal inputs which indicated 2:1 summation. Marks (1974, p. 168) has interpreted such findings (e.g., those of Scharf and Fishken, 1970) as evidence for linear binaural summation of loudness that holds across all input levels. Levelt, et al. (1972), also obtained evidence for linear summation under conditions of unequal binaural levels. However, Mulligan et al. (1982), have shown that the magnitude of summation that occurs depends on the interaural phase of the binaural tone, a stepwise increment occurring in the vicinity of the Hornbostel-Wertheimer constant.

Monaural loudness summation occurs within critical bands (Zwicker and Scharf, 1965). Essentially, it is this summation that accounts for the

masking of tones by noise within critical bands (Fletcher, 1940). Summation of the loudnesses of tonal signals close enough in frequency to fall within the same critical band is assumed to be linear (Marks, 1979). However, loudness may summate across critical bands as well, as shown by Zwicker and Feldtkeller (1955) and Port (1963) who found that loudness of a band of noise increased as its bandwidth increased beyond the width of a critical band even though the overall level of the noise was held constant.

Masking noise has been shown to alter the loudness of tones (Stevens and Guirao, 1967; Hellman and Zwislocki, 1964; Richards, 1968; Stevens, 1966). As noise level increases, sound pressure level of a tone has to be increased in order that its loudness remain constant. Generally a tone of a given sound pressure level will appear less loud under noise conditions than in quiet. Furthermore, the steepness of loudness functions increases as noise level increases. This seems to be the result of raised thresholds due to masking with a consequent reduction in the dynamic range of intensity between threshold and peak loudness. The growth of loudness is thus more rapid in noise than in quiet.

17. Is recognition of the loudness and sound quality of tones influenced by the temporal proximity of other sounds?

Based on the outcome of a single study, the answer appears to be yes. In a backward recognition masking experiment, Moore and Massaro (1973) found that recognition performance improved on both the loudness category dimension and the sound quality dimension as the signal-masker interval

increased. Brief intervals resulted in poor recognition performance (but see question 71). When attention was directed either to the loudness dimension or the sound quality dimension, performance was no better than when attention was directed to both dimensions. Apparently, listeners were unable to improve their performance by selectively attending to a single dimension if the signal-masker interval were brief. However, this effect might be the result of uncertainty on one, or both dimensions.

18. Given a complex mixture of acoustic inputs, can listeners selectively attend to one message, component, etc., contained within the complex?

As long ago as 1863, Helmholtz (1954) was attracted to the fact that, in listening to an orchestral performance of some musical composition, a person may selectively hear one or another of the various musical instruments in near isolation. In a sense, this is an extraordinary fact since the waveform arriving at the eardrum in such a situation is exceedingly complex, containing the combined sound waves produced by all of the musical instruments being played in concert. To be able to hear a single instrument amongst the many requires that the auditory system perform some analysis on the complex waveform such that the sounds peculiar to any one instrument will be filtered out. Since the time of Helmholtz the fact of selective auditory attention has been well documented, but the filtering process by means of which it occurs has yet to be understood. A situation comparable in human experience with the concert hall phenomenon of Helmholtz is the cocktail party problem described by Cherry (1957, p. 278). The problem refers to our ability to

listen to, and follow, the voice of one speaker in the midst of a cacophony of voices of other speakers all located, perhaps, within the same room (see question 39). Again the problem is one of extracting out of the noise the relevant signal or message.

19. What factors increase the probability that an observer will respond selectively to one message presented simultaneously in a complex of other messages?

Successful communication requires more than successful signal transmission and reception. The message borne by the signal must compete effectively for the listener's attention. As Broadbent (1958) showed in his classical treatise on Perception And Communication, the factors that contribute to effective communication derive from three interdependent classes of parameters--signal, message, and listener. Under conditions where listeners are subject to heavy task loadings, high noise levels, high rates of signal transmission and simultaneous message reception, etc., the probability that any one message will be received, processed, and responded to appropriately is reduced. Consequently, optimization of communication requires that signals be selected and messages constructed with careful attention to the processing characteristics of the receiver--in this case a human listener.

Critical factors may be separated into three groups: distinctiveness, continuity, and relevance. The factors which contribute to physical distinctiveness of signals include spectral composition, frequency

relationships among tonal components, signal intensity, signal-to-noise ratio, and point of origin in space. For example, spectral composition contributes to the distinctiveness of male and female voices; certain frequency relationships among tones must be maintained for chord recognition: an intense sound is more likely to attract attention than a weak sound; noise is less likely to produce masking under high signal-to-noise ratios; and two simultaneous audio messages are more likely to be distinguished if they originate from different points in space.

Factors that contribute to the perceptual continuity among the successive components of an auditory message include semantic content, grouping variables, and pattern structures. For example, one of several simultaneously present messages will be more likely to hold the listener's attention if its successive components are related by meaningful semantic information; the successive components in an auditory message are more likely to form perceptual groups ("streams") if tonal frequency disparity is not too great and the rate of presentation is adequate; likewise, sounds possessing the same spectral structures ("timbre") are more likely to be grouped than those with different spectra; and the patterns among successive components within auditory trains are more likely to emerge if pattern structures are manifest in rhythmic repetitions, ascending and descending pitch contours, etc.

Factors that contribute to message relevance are less definitive and generally depend on the significance of the signal to the listener as well as the listener's preparedness to respond selectively. In this connection, both the information and task loads to which the listener is

subject, as well as the listener's set to respond, contribute to the outcome of a signal transmission. For example, if the information load on the auditory channel is heavy, transmission of the listener's name would have a higher probability of getting the listener's attention than some neutral word. Similarly, emotionally sensitive words would have a high probability of attracting the listener's attention. However, even an otherwise neutral word for which the listener had been set to respond would prove far more effective than if the listener had not been so set. If physical distinctiveness is combined with relevance, the signal may be made even more potent. For example, against a background of male voices a spectrally different female voice speaking the listener's name will prove more effective than if it were spoken by a male voice. Furthermore, adding the dimension of continuity, if a female voice continued speaking at the proper rate, and with an appropriate rhythm, after pronouncing the listener's name, the likelihood that the listener's attention would be held throughout the message without interference from competing messages would be enhanced.

20. Is response set an effective mechanism for isolating relevant information contained within concurrent competing signals?

It would appear that the answer to this question has to be a qualified yes, that is, set is an effective mechanism for isolating relevant information provided the auditory messages are physically distinctive. An example of the operation of response set in auditory selection is provided in an experiment by Moray and O'Brien (1967). They found that one of two

simultaneous auditory messages presented dichotically could be monitored and "critical" items that were contained within it could be selected out by listeners almost as accurately as could be done when the monitored message was presented alone. It is important to note that, in this study, the two dichotic messages were readily distinguishable on the basis of auditory location and, therefore, offered a physical basis on which selective attention could operate. Also, the "critical" target items differed physically from the message context in which they occurred and could thus be picked out by listeners set to detect them. In Moray and O'Brien's study, listeners were set to monitor one of the two messages just as they were set to detect target items introduced into it. Hence, response set was effective in blocking the irrelevant message and in picking out the monitored message target items.

21. If a listener has no prior set to respond selectively to either one of two messages, what will determine which message will be selected, if either?

It would appear that, under conditions of exposure to several simultaneous messages, if a listener can identify a relevant message, he will have relatively little difficulty thereafter in following it. This assumes, of course, that the continuity of the selected message is adequate to prevent intrusions of irrelevant material from competing messages. Assuming this to be the case, the problem of message selection by passive, or non-set listeners reduces to a matter of those factors that may contribute to initial attentional orientation to a particular message. Tolhurst and Peters (1956) examined this problem in an experiment with simultaneous

dichotic messages. Their listeners were given no instructions regarding which message they were to select. They found that the more intense of the two messages had the higher probability of being selected. In fact, as the intensity ratio of one message to the other increased the probability of its reception increased. It would appear that this is not merely a matter of physical distinctiveness, but more a matter of physical prominence. We make this distinction because, even when response set is in effect, some physical distinctiveness is necessary for attentional selectivity to operate upon. Moray (1970 C, p. 45) suggests that "... features such as pitch, loudness and perhaps rhythm can help a listener to identify one of two or more messages which are presented either monaurally or binaurally; after this the structure of the message itself allows the listener to continue to select it." While we concur in the general thrust of Moray's remarks, we would argue that, while physical distinctiveness along the psychological dimensions of pitch, loudness, etc., may be sufficient for following a message to which a listener is already attending, initial identification of the message especially in the absence of response set depends heavily upon the physical prominence of the leading portion of the message. By prominence we mean relative magnitude on some physical dimension, e.g., the magnitude of the ratio of intensities, signal-to-noise ratios, spectral differences, etc.

22. Is the detection of signals in noise any better if the observer has prior information about the physical characteristics of the signals?

In psychophysical signal detection situations, knowledge of signal frequency, signal amplitude, time of signal arrival, etc., can improve

human detection performance. Swets (1963) found that such knowledge increased human performance to within about 3 dB of the ideal observer's performance. By contrast, complete uncertainty about the physical characteristics of the signal reduced detection performance by as much as 12 to 15 dB below that of the ideal observer. Based on our own experience with signal detection methodology (e.g., Mulligan et al., 1968), we do not feel that this is simply a case of "voluntary tuning," as Swets suggested. Considerable practice is necessary to familiarize listeners with signal frequency, amplitude, time of arrival, etc. Swets' listeners required extensive practice to achieve the "voluntary" selectivity they exhibited. However, even if this sort of tuning requires training to achieve, the potential for improvement in auditory selectivity is sufficiently great that the expenditure of effort may be justified under certain conditions.

23. Do observers experience more difficulty in identifying or in tracking relevant messages?

If a listener received a single short-duration auditory message, assuming the signal-to-noise ratio were sufficiently high, it seems doubtful that there would be any difference of a measurable magnitude between identification and tracking proficiency. Indeed, to question whether one or the other is more or less difficult under these conditions may not be meaningful. If there is but one message which can occur, there is little to identify. And, if the message is brief, there is little to track.

Perhaps, in this case, detection is the more appropriate term, especially if signal-to-noise ratio is low.

The question of message identification suddenly becomes meaningful if the listener is confronted with two or more messages from which he must pick the relevant one. Broadbent (1952) presented listeners with two simultaneous auditory messages, each of which was associated with a particular visual "call sign," i.e., cue. On presentation of a visual cue, the listener had to identify the auditory message associated with it and then track the message. Broadbent found that listeners experienced more difficulty in identifying the correct message than in following it once the identification had been made. Thus it would appear that, once a listener's attentional mechanism is locked upon the flow of a message, the most difficult part of the task has been surmounted. It is in the initial searching out of the relevant message from a complex of such messages that listeners encounter difficulty.

24. Given inputs to two modalities, or to two channels within the same modality, can human observers accurately identify simultaneous events contained in the two inputs?

The findings of Sternberg and Knoll (1972) indicate that the answer to this question is no. Observers attempting to judge the simultaneity of two signals show systematic errors in the direction of the attended input. That is, the signal on which the observers focus their attention

is consistently judged to occur sooner in time than the non-attended signal. This is known as the "law of prior entry."

25. Can two simultaneously ongoing messages be processed at the same time by human observers?

This is the classical problem of divided attention. Overload difficulties experienced by air-traffic controllers appears to have provided the original impetus for research in this area. The early work includes that of Broadbent (1952, 1954), Mowbray (1953, 1954), Poulton (1953), Speith, Curtis, and Webster (1954), Webster and Thompson (1954), Webster and Solomon (1955). The general finding of these studies was that human observers either cannot process simultaneous messages or do so under some conditions with difficulty (also see questions 76 and 85). The exception appears to exist only for highly redundant messages (Webster and Thompson, 1954).

26. Can human observers recall two, brief messages presented simultaneously in different modalities or channels?

Surprisingly, the answer to this question is yes so long as the messages are brief and distinguishable. By distinguishable here we do not mean merely that, for example, the digits 1, 2, 3 are noticeably different than the digits 4, 5, 6. Rather, we mean either that the two messages are presented to different modalities (one visually and one auditorily) or, to

the same modality in different voices (one male and one female), or from different spatial locations (also see question 65). The original experiment in which observers were shown to be able to recall two, brief messages presented simultaneously in different channels was reported by Broadbent (1954). In that experiment, simultaneous pairs of messages consisting of 3 digits each were presented through separate channels to each ear of a listener. Consequently, the two messages were spatially separated. The listener's task was to reproduce all 6 digits in any order. In a significant number of cases, listeners were able to perform this task adequately. Typically, listeners reported the 3 digits heard at one ear before reporting the 3 digits heard at the other ear even though both sets of digits were presented simultaneously to the two ears. In no case were the digits from the two channels ever mixed in the recall report. This methodology has come to be known as the "split-span" experiment of Broadbent. Cross-modality effects are discussed in questions 81 through 90.

27. Is recognition-memory for information presented simultaneously in two channels (dichotically) as good as recognition-memory for information presented in one channel?

Based on a study by Levy (1971) which involved relatively long messages (31 words), the answer is no. It was found that observers may store some of the two-channel information, but recognition performance was far poorer than in the one-channel case. Listeners optimized their performance by adopting a "passive" attitude rather than attempting to attend selectively

to either one of the two messages. This passive attitude was reflected in the lack of any correlation between recognized members of dichotic pairs of stimuli. In an unpublished study by Avner (described by Kahneman, 1973), shorter dichotic messages were presented and it was found that listeners adopted a more active listening attitude. As a result, a consistent negative correlation was found between simultaneous item pairs on the recognition test. Evidently, the recall of one member of a dichotic pair was associated failure to recall the other member. The focusing of attention on the input at one ear, thus, effectively blocked recall of a simultaneous input to the other ear. It appears that the shorter messages used by Avner encouraged a more selective listening attitude in which listeners first attempted to focus on the input to one ear and then switch attention to the input at the other. The negative correlation obtained by Avner suggests that this strategy was not successful. Perhaps, if the two simultaneous messages had been as brief as those used by Broadbent (1954), a positive correlation might have been obtained. It appears that the channel-switching strategy in the latter case was successful. By contrast, the very long dichotic messages used by Levy probably discouraged any form of attentional strategy. The overall implication of these findings is that recall of separate simultaneously presented messages will be optimized if they are very brief. Considering a speculative practical extension of these findings, if a listener is already attending to inputs at one ear, brief inputs to the other ear may prove less disruptive and have a higher probability of being recalled than long inputs.

28. Can observers identify (label) different stimuli presented simultaneously as well as they can identify the same stimuli presented one at a time?

According to the results of several studies conducted by Lindsay and his co-workers, observers can identify different simultaneous inputs nearly as well as they can identify the same inputs if presented one at a time provided the inputs are easily discriminable. For example, if inputs to different modalities are readily discriminable, then they can be identified about as well when presented simultaneously as they can when presented singly. However, if discriminability of the signal in a given channel is reduced, then performance breaks down under multi-channel conditions (Lindsay, Cuddy and Tulving, 1965; Tulving and Lindsay, 1967; Lindsay, Taylor and Forbes, 1968). It appears that, if inputs are individually highly discriminable, concurrent presentation of them will not deteriorate significantly their identifiability.

29. Can listeners respond appropriately to long messages while, at the same time, receiving them?

This question has received considerable scientific interest since the original experiments were performed by Cherry (1953). Utilizing the technique which has come to be known as "auditory shadowing," researchers ask the listener to repeat back one of several relatively long messages while receiving them. Another term for this technique is "verbal tracking." The general finding has been that listeners can successfully repeat one of several continuous auditory messages as they are occurring

with a high degree of accuracy. This technique has provided researchers with an important tool for studying auditory attentional processes. The effect of shadowing a message presented at one ear is a nearly complete attentional block, or rejection, of a simultaneous message at the opposite ear. A review of the early literature on shadowing is provided by Moray (1970c).

30. What two tasks have been utilized most often in studies of auditory attention?

According to Kahneman (1973), the two most utilized tasks in the study of auditory attention have been shadowing tasks and monitoring tasks. The shadowing task was described in the preceeding question. In the monitoring task, the listener attends to one of several messages, usually continuous, in an effort to detect the occurrence of target signals. The listener is instructed to respond overtly only to the target signals. The application of this task to the study of target detection in messages is an extension of the "listen and answer" technique (this is Moray's term). In this technique, listeners selectively monitor one of several messages and then attempt to respond appropriately to the information (question, directions) contained within the relevant message. Broadbent (1958), appears to have been the first to see the monitoring technique as constituting a valuable tool for the study of attentional processes.

31. Who performed the original studies employing the "speech shadowing" technique?

It appears that the original studies were conducted by Cherry (1953), Moray (1959), Treisman (1960). Since this early work, however, numerous studies have been conducted on dichotic listening using the shadowing technique.

32. Given two auditory messages, one of which is to be shadowed and the other ignored, how effective is the observer's performance? That is, how effective is attentional selection and rejection as evaluated in shadowing performance?

Provided the shadowed and rejected messages are distinguished by an obvious physical characteristic (e.g., spatial origin), shadowing performance will be nearly as good in the presence of the competing message as it is without it (Cherry, 1953; Cherry and Taylor, 1954). In studies using dichotic presentations of messages through independent channels (separate headphones), Cherry found that listeners were always aware of the presence of the competing message on the non-signal ear, but they were unable to report hardly anything about the contents of the message when subsequently questioned, not even the language in which it was spoken (also see question 74). Listeners were not even aware of a switch to inverted speech in the rejected message. However, in studies by Lawson (1966), and Treisman and Riley (1969), it was found that listeners were aware of the speaker's sex (male and female voice) on the rejected

channel. Also, listeners were able to detect any major physical change (change in voice, a switch from voice to tone, or the occurrence of an isolated sound) on the rejected channel. Apparently, the introduction of novel changes in the rejected channel are attention-getting, or distracting (see questions 49 through 52). Although stimuli that will command attention when introduced into the rejected channel are most effective as distractors when they are physically distinctive, this is not a violation of the general rule that shadowing is most effective when the inputs to the two channels are distinctive. Once the attentional selection of channels is made with respect to what is distinctive, then a departure from that status constitutes a novel change that can be noticed.

33. How resistant to intrusions is the attentional rejection of one message due to shadowing of another message? How complete is the attentional rejection?

As stated in the previous question, attentional rejection due to shadowing is highly effective except for novel changes that occur in the rejected channel. Also, signals of special significance to the listener that are introduced into the rejected channel have been found to break through the attentional block (Moray, 1959). A number of studies over the years have been directed at answering the question, how complete is the attentional block produced by auditory shadowing (Miller and Selfridge, 1950; Moray and Taylor, 1958; Taylor and Moray, 1960; Moray and Barnett, 1965; Moray, 1966; Moray, 1970a; Treisman, 1965; Harrison, Moray and Treisman, 1970). It has been found uniformly that it is the content of the rejected

message that is not processed by listeners. The general characteristics of the rejected signal, however, do not appear to be blocked by shadowing. Furthermore, presentation rates may be a factor, as may the redundancy of the material. If presentation rate is slow, or if the material is highly redundant, "attention wanders" and portions of the rejected message are picked up. Nevertheless, even when the rejected message is normal prose and the shadowed message consists of varying degrees of statistical approximations to prose, the attentional block due to shadowing remains effective. Rather than switching to the more easily predictable rejected message, listeners tend to doggedly follow the selected message. As Moray (1970c) commented, listeners ". . . stuck grimly to the difficult task of handling the nonsense which poured into their ear through the "acceptable" channel. Shadowing errors under these conditions, however, did increase.

34. What characteristics of auditory messages can serve as a basis for attentional selection if concurrent messages are presented monaurally? Binaurally?

This question reduces to the following: What differences between messages will promote, "facilitate," attentional differentiation of messages? A variety of experiments have been conducted in search of answers to this question (Broadbent, 1952; Cherry, 1953; Egan, Carterette, and Thwing, 1954; Spieth, Curtis, and Webster, 1954; Tolhurst and Peters, 1956; Broadbent, 1958). A number of characteristics have been found to be effective, if not necessary, in promoting attentional differentiation

between messages. Monaural characteristics include (1) message spectral composition (as in the pitch of a voice), (2) transitional probabilities between words and phrases within messages, (3) call sign identification of relevant messages, (4) message loudness or intensity, and (5) message onset characteristics. Binaural characteristics include all of the above that are effective monaurally, provided they occur as interaural differences. In addition, interaural time differences are indicative of different spatial origins of messages and have been found to be one of the most effective cues for attentional differentiation. In conclusion, it would appear that the completeness of attentional rejection of irrelevant messages is greatest when the message being attended to is readily distinguishable (see question 39).

35. Under what conditions will listeners switch attention from the shadowed message to the rejected message?

Research has indicated that listeners shadowing one of two simultaneous, dichotic messages tend to switch attention from the shadowed message to the rejected message either unintentionally or deliberately. The conditions responsible for these attentional switches have been noted in a number of reports (Moray, 1959, 1966, 1970a; Miller and Selfridge, 1950; Moray and Taylor, 1958; Taylor and Moray, 1960; Moray and Barnett, 1965; Treisman, 1965; Harrison, Moray and Treisman, 1970). In the category of voluntary switches of attention, it has been found that listeners can switch from one channel to another if instructed to do so, or if signaled to do so by presentation of a call sign. It has also been found that, if

listeners have been instructed to attend to a particular channel regardless of the message it contains, if the message is then switched to the opposite channel, listeners tend to follow it at least temporarily before switching back to the designated channel.

In the category of involuntary switches of attention, attentional shifts to the rejected signal appear to be largely confined to conditions in which the relevant message is difficult to follow. For example, if the relevant and irrelevant messages are nearly indistinguishable, attentional switches tend to occur. If the continuity or semantic coherence of the attended message is low, or if the rate of presentation of the attended message is either too slow or too fast, attentional switches will tend to occur. In each of these cases the attended message has been somewhat degraded.

Attentional shifts from the attended message to the rejected message may, however, occur even if the attended message is readily distinguishable, coherent and presented at an optimal rate. This exception occurs if a novel or an especially relevant signal is introduced into the rejected channel (see questions 49 and 50). Metaphorically, novel and peculiarly relevant signals act as "attentional magnets," especially if they are relatively distinctive (see questions 51 and 52).

36. If one of two simultaneously presented dichotic messages is shadowed, will attention shift to the rejected message if it is made more intense than the one that is shadowed?

Unlike the situation in which the listener is not set to attend to either one or the other of two dichotic messages, in the shadowing situation the listener is set to attend and respond to one of the messages. In the former case, attention will be attracted to the more intense of the two signals. However, the attentional focus required in shadowing one of two simultaneous messages effectively blocks the unattended message even if it is the more intense of the two. This was the finding of Moray (1958) who studied the effect of intensity relations between unattended and attended messages during auditory shadowing. He found that, by increasing the intensity of the unattended signal, errors in shadowing performance increased, especially errors of omission. Moray reported that the effect of making the unattended message more intense appeared only to increase the "noise" background for the shadowed signal. Similar results were obtained by Egan, et al. (1954), who employed the auditory monitoring technique in dichotic listening experiments. Thus, it appears that, once a listener's attention is locked onto a given message, more intense competing messages will be ineffective in switching attention even though errors in following the attended message may increase. In fact, moderate intensity differences between messages (even where the unattended message is the more intense one) might contribute to message distinctiveness and, thus, may facilitate attentional differentiation of the two messages.

37. Does ear dominance influence the selection of one of two simultaneously presented dichotic target signals?

Kahneman (1973) presents the findings of experiments conducted by Avner (1972) and Colavita (1971) which indicate a tendency in some listeners to attend more readily to signals presented singly at one ear as compared with the other ear. Furthermore, pronounced ear dominance may occur if pairs of target signals are presented simultaneously to the two ears, i.e., dichotically.

38. Can listeners rapidly switch attention from the input at one ear to the input at the other?

It appears that, not only can listeners not switch attention rapidly from one channel to the other, but that reorientation of attention after a period of selective listening takes some time and is difficult. In an experiment in which listeners were required to monitor a message consisting of successive words at one ear and to detect target signals (digits) contained within the message, Gopher and Kahneman (1971) found that listeners experienced considerable difficulty in responding appropriately to an auditory reorientation cue that indicated which of the two ears the listener was to monitor for target signals. The results of this experiment showed that, for a few seconds after presentation of the reorientation cue, intrusions from the unattended channel and confusions between channels occurred. Interestingly, Gopher and Kahneman (1971) also reported that the error rates that were obtained in their experiments were

negatively correlated with proficiency of military pilots. Furthermore, Kahneman et al. (described in Kahneman, 1973), reported that error rates on the same task were found to be negatively correlated with the safety records of bus drivers (also see question 67). Perhaps speed in switching attention would be a useful predictor of success in occupations requiring rapid changes in perceptual orientation.

39. By what means does a listener select one voice from a complex of voices speaking at the same time?

This is the classical "cocktail party problem," so named by Cherry (see question 18). It is well established that attentional differentiation of messages depends heavily upon the degree of *physical distinguishability* of the messages. Distinguishing characteristics that can be resolved monaurally include spectral composition, intensity, onset transients, and the transitional probabilities that exist between the words and phrases constituting the message. In addition to these characteristics, binaural time and intensive differences at the two ears enable the listener to differentiate the location of the message source in space (see question 34). The work of Cherry and Sayers (1956), indicates that such directional cues provide the primary basis for voice selection. Presumably, Egan, Carterette, and Thwing's (1954) finding that messages can be better resolved if presented to the ear opposite that receiving noise can be interpreted partly in terms of directional cues. Not only was the message at the noise-free ear not subject to masking by the

message at the contralateral ear, but the two inputs were spatially separated and, thus, more easily attentionally isolated (see question 47).

40. If more than one concurrent message requires a differential response, will separation of the messages in "auditory space" facilitate performance?

Research has shown that spatial separation facilitates attentional differentiation among simultaneous signals. Any tendency to select one of two signals presented simultaneously will thus be enhanced by spatial separation as in dichotic presentation with a corresponding increase in responsiveness to the attended signal. This will be correlated with a decrement in response to the unattended signal. Spatial separation can not, therefore, improve performance when each of the two simultaneous dichotic signals requires a response. The exception to this may occur if dichotic pairs of messages are very brief (Broadbent, 1958; see question 26).

41. What distinguishing characteristic of auditory signals is most effective in facilitating selective listening under multi-signal conditions?

Research cited in foregoing questions has indicated the importance of spatial separation for attentional differentiation among messages. Studies which indicate that perceived differences in spatial locations of sound sources is, perhaps, the most effective distinguishing characteristic for selective listening under dichotic conditions are those

of Poulton (1953), Spieth, Curtis, and Webster (1954), and Treisman (1964b).

42. If two or more simultaneous auditory signals originate from the same point in space, or are presented at the same ear, what physical cues are available to permit attentive selection of one signal from among the complex?

If spatial separation is eliminated as a cue, the relevant signal may, nevertheless, be isolated on the basis of its pitch or loudness, but only with some difficulty (Treisman, 1964b). If, in addition to spatial separation, pitch and loudness differences are largely eliminated by having two messages produced by the same voice, attentional isolation of the message becomes even more difficult. For example, if the messages are delivered in the same voice, but in two different languages (French and English), isolation of the English message even by English speaking listeners is poor (Treisman, 1964a). These findings indicate that, in the absence of spatial cues, other distinguishing cues (pitch, loudness, even linguistic differences) contribute relatively little to attentional selection. With binaural separation of messages, however, these same cues appear to exert a much more prominent influence.

43. Do localization cues contribute to temporal resolution of rapid sequential signals?

To the extent that dichotic inputs delivered through headphones independently to the two ears are equivalent with auditory spatial localization, there is some reason to believe that localization cues do contribute to improved temporal resolution of rapid sequential signals. It has been shown that the apparent rate of a series of clicks is lower when the clicks are alternated between the two ears than when they are presented to one ear, or simultaneously to both ears (Axlerod, Guzy and Diamond, 1968). In addition, Axlerod and Powazek (1972) found that the apparent click-rate increases as the spatial separation between sound sources is reduced.

44. Can listeners reject two messages while shadowing a third message?

If two messages are presented to the same ear, listeners will lateralize them both to the same spatial position. If two messages are presented independently to the two ears, they will be lateralized to different points in space depending upon the interaural time delay between onsets of the two messages. If a third message is added to one or the other ear, its spatial location will likewise be determined largely by the interaural time relations that exists between it and the other messages. By manipulating such interaural temporal relations among messages, Treisman (1961, 1964a, b) was able to study the effect of lateralization on the effectiveness of auditory selection. Effectiveness of selection was

measured in terms of the amount of interference produced by unattended messages. It was found that listeners can reject two messages while shadowing a third, but more interference was produced by two rejected messages than by one. The least amount of interference was obtained when the two rejected messages were lateralized to the same position while the shadowed message was lateralized to the opposite position. A greater amount of interference was produced by the two rejected messages if one of them was lateralized at each ear with the attended message centered in auditory space between them. The greatest amount of interference was obtained with one rejected message and one attended message, both of which were lateralized at the same spatial position. Although it was possible in this case for listeners to shadow the attended message, the absence of any apparent spatial separation between messages rendered the task difficult. Incidentally, Treisman found that shadowing under this condition was considerably easier if one of the voices was spoken by a male and the other by a female. Treisman also found that, if the unattended message was in a foreign language unknown to the listener, or in a technical jargon the meaning of which was not understood by the listener, attentional selection of the meaningful message was easier.

45. Does the temporal continuity of irrelevant messages contribute to the effectiveness of selective attention?

The findings of Henik (described by Kahneman, 1973) indicates that the answer to this question is yes. Henik's index of the effect of irrelevant messages was the number of intrusions of items from the irrelevant message

in recognition tests. It was found that the number of irrelevant intrusions varied as a function of the rate of presentation of irrelevant items in the unattended message. At slow rates of presentation the number of irrelevant intrusions was greater than at higher rates. The explanation for this finding seems to be that, at high rates of presentation, the irrelevant items formed a continuous message which could be rejected more easily. At slow rates of presentation the irrelevant items lacked temporal continuity and were, consequently, more intrusive. It seems likely that the rules governing perceptual grouping and auditory pattern structures (see questions 7 and 8) could be used to predict the effectiveness of auditory selection under such conditions as those investigated by Henik.

46. If listeners shadow one of two identical messages presented at the two ears, one of which is delayed relative to the other by a time difference  $\tau$ , at what value of  $\tau$  will the two function as different messages?

Employing an experimental design originated by Cherry (1953), and explored by Moray (1960), Treisman (1961, 1964c) varied the interaural difference in times of arrival of identical messages at the two ears in an effort to determine the magnitude of the delay required for listeners to become aware that the rejected message was identical with the attended message. Treisman found that, if the shadowed message lead by ten seconds (20 words), or if the rejected message lead by one or two seconds, listeners recognized the two messages as identical. This result suggests different processing times for rejected and shadowed messages (see question 53).

However, why this should occur does not appear to be understood.

Incidentally, Treisman also found that listeners were able to recognize the identity of the two messages even when they were spoken in different voices. Even more remarkable was the finding that bilingual listeners often recognized the identity of messages delivered in two languages (also see questions 54, 55, and 58).

47. Can auditory messages be better resolved if presented to the same ear receiving noise or if presented to the contralateral ear?

This question was carefully investigated by Egan, Carterette, and Thwing (1954). They measured the detectability of one message in the presence of another, and the articulation score for one message in the presence of another, as a function of the relative intensities of the two messages. These two performance measures were obtained under both monaural and dichotic listening conditions. They found that the threshold for detectability of the signal message was only slightly influenced by increases in the intensity of the competing message under the dichotic condition, i.e., when the competing message, or noise, was presented to the opposite ear (see question 39). By comparison, when the competing message was presented to the same ear as the signal message, increases in the intensity of the competing message resulted in a typical masking function. Threshold for detectability of the signal message increased as a nearly linear function of the intensity of the competing message. Likewise, there were marked differences in articulation functions for dichotic and monaural listening. In the dichotic condition, the

articulation score increased rapidly to asymptotic level as the ratio of message intensity to noise intensity increased. In the monaural condition, however, an S-shaped function was obtained such that, at signal-to-noise ratios below zero (the ratio in decibels at which signal intensity equals noise intensity), performance increased gradually as a positive acceleration. At signal-to-noise ratios greater than zero, articulation performance increased rapidly in a negative acceleration toward asymptote.

The functions for dichotic and monaural listening thus are widely separated and differently shaped. Under dichotic conditions the signal message can be as much as 20 dB below the competing message and the articulation score will be near maximum. However, if both messages are presented to the same ear, the signal message must be about 10 dB greater than the competing message in order to achieve a comparable articulation score. Clearly, auditory messages are better resolved under dichotic listening conditions (Licklider, 1948; Hirsh, 1948).

48. Can observers monitor information presented in one channel without intrusion of irrelevant information from a second channel if they expect important signals to be delivered in the second channel?

This question was examined by Weg (described in Kahneman, 1973) who required listeners to monitor an ongoing message in one channel while remaining ready to detect signals designated as important in the other channel. The unmonitored channel also contained a message which served as

a background against which the signals were detected. In this sort of experiment the message in the unmonitored channel is not rejected in the sense that it is in a shadowing experiment. It was found that the expectancy for important signals in the unmonitored channel resulted in massive intrusions of irrelevant material from the message in the unmonitored channel. A recognition test showed that listeners "recognized" items they attributed to the message in the monitored channel only 40% correctly. Of the items incorrectly "recognized" as belonging to the monitored message, 44% actually originated from the message in the unmonitored channel, and 16% were listener inventions. An improvement in performance was obtained by using signals against a background message spoken by a female voice. In this case, 53% correct recognitions occurred. There were 34% intrusions and 13% listener inventions. In a similar study, Avner (also described in Kahneman, 1973) obtained essentially the same results. These findings seem to indicate that the more distinctive target signals require less vigilant monitoring and, consequently, permit more focusing of attention on the monitored message and less on the unmonitored message.

49. Will a listener who is shadowing a message presented at one ear be more likely to notice a message at the other ear if it is preceded by the listener's name?

In the study by Moray (1959), listeners were instructed to shadow a message at one ear while ignoring an irrelevant message at the opposite ear. It was found that, when the irrelevant message was preceded by the

listener's name, shadowing performance diminished. This indicates that the introduction of the listener's name into the unattended channel was effective in switching attention to the message in that channel and, consequently, diminished the listener's ability to continue shadowing. Signals that are especially relevant to the listener, when introduced even unexpectedly, usually succeed in attracting attention (but see question 50). The attention-getting power of the listeners' names in Moray's experiment was, evidently, great since the attentional rejection of the irrelevant message in shadowing experiments has been shown to be nearly complete.

50. Will stress-associated signals contained in a rejected message affect a listener's ability to shadow a second message simultaneously present at the contralateral ear?

Surprisingly, Corteen and Wood (1972) found that the answer to this question was no. In their experiment city names were associated with electric shock during a pre-conditioning session. Using the dichotic shadowing technique, the shock-associated city names were embedded within the rejected message. It was found that, although the city names were effective in eliciting galvanic skin responses, the listeners were not aware of these signals, nor did they impair performance on the shadowing task. There can be little doubt that the shock-associated names were received and processed by the listeners' nervous systems since they were successful in eliciting GSRs. That they were unsuccessful in attracting attention to the rejected message was unexpected (see question 49) in

light of Moray's (1959) finding that listener's names that preceded onset of the rejected message were effective in getting attention. Perhaps, if the shock-associated city names had preceded the rejected message (as in Moray's experiment), a different outcome might have been obtained in Corteen and Wood's experiment (see question 68). Conversely, the listener's names in Moray's experiment might have proved ineffective had they been embedded in the rejected message (but see question 75). The matter is worthy of further investigation since it implies a limitation upon the usefulness of particularly relevant signals as attention-getters.

51. Does physical distinctiveness aid in the detection of target signals in unattended (rejected) messages?

It appears that the answer to this question is clearly yes. In a study by Treisman and Riles (1969), target signals presented in a voice that differed from that of the non-signal part of the message (background) were always detected in the unattended channel. In another study by Lawson (1966) a tone signal was introduced into a speech background. It was found that the tone was easily detected in the unattended message.

52. Will distinctive target signals more effectively block competing messages than non-distinctive targets?

There can be little doubt that distinctive signals are more detectable than non-distinctive signals. For example, as signal-to-noise ratio

increases, the detectability of signal messages against a noise background increases (Egan, Carterette, and Thwing, 1954). In the case of tonal signals, detectability also increases as a function of signal-to-noise ratio, depending on signal frequency (Mulligan and Elrod, 1970). In this case the distinctive characteristic is the relative intensity of the signal. Data more directly applicable to this question was obtained by Weg and Avner (described in Kahneman, 1973). They found that, in a dichotic listening situation, distinctive signals introduced into the unattended channel could be more readily monitored than less distinctive signals and, consequently, enabled better recognition performance on the attended message (but see question 72).

While these studies show that signal detectability improves as signal intensity relative to the background noise intensity increases, it should be pointed out that this effect is usually attributed to a decrease in masking. Masking is understood to be a corruption of the signal by noise which cannot be counteracted through filtering in the peripheral auditory system. Presumably, attentional selection takes place more centrally and could not account for any decrease in masking. We would not want to say that detectability improves as a function of signal-to-noise ratio because the noise is more effectively blocked through selective attention at higher relative signal intensities. Rather, both selectivity and detectability may improve as a function of signal-to-noise ratio. The question of signal distinctiveness and selectivity needs further investigation.

## 53. Does temporal priority among messages contribute to message selection?

In a dichotic listening situation, if one of the two messages arrives at one ear prior to arrival of the other message at the opposite ear, the listener's attention will be attracted to the first message to arrive and, in the absence of any strongly compelling motivation to switch channels, the listener will continue to monitor the first message even after the delayed message arrives at the opposite ear (see question 46). An impressive body of research (Broadbent, 1955, 1958; Speith, Curtis and Webster, 1954; Poulton, 1956; Moray, 1970a; Schubert and Parker, 1955) indicates that any feature which helps to distinguish any message from another will make it more probable that the more distinctive message will be selected and the other rejected.

## 54. Is attention selective for semantic continuity of auditory messages?

Treisman (1960) conducted an interesting experiment in which the attentionally selective strength of semantic continuity was tested directly. The shadowing technique was employed since this task usually results in a very high level of channel selectivity and thus provides a strong test of the question. As is usual in this technique, listeners were instructed to attend to the message at one ear only, say, the right ear. Different messages were presented simultaneously to the two ears and, some time after onset, the messages were switched to opposite ears. Redundancy of semantic content in the messages was high, as in connected prose, thus optimizing continuity through the messages. It was found

that, when the shadowed and irrelevant messages were switched from ear to ear, the listeners tended to follow the attended message to the incorrect ear for a few words before reverting back to the selected channel (see question 60). Most listeners reported that they were unaware of the transition. These results indicate that semantic continuity may be strong enough to overcome channel selection even if only momentarily (also see question 46).

55. Can attention to a message at one ear block reception of semantic continuity of a message delivered simultaneously to the opposite ear without blocking reception of its general characteristics?

In the classical experiment on auditory shadowing by Cherry (1953), it was found that the answer to this question is yes. Cherry's listeners were completely unaware of the content of the message in the rejected channel, but they could reliably say whether the distracting message was speech or non-speech, whether it was spoken by a male or a female voice, or whether it consisted of a series of disconnected words or continuous prose. These findings were later confirmed by Moray (1959) in all important respects. Further experiments on shadowing by Treisman (1965a, b), however, indicate that listeners may not be completely unaware of the content of the rejected message. If the rejected message was presented in a foreign language, it was more easily blocked than if it was presented in the listener's native tongue. Also, bilingual listeners were able to recognize the identity of the rejected and shadowed messages even when they were in different languages (see question 58).

Treisman's findings suggests that the block for semantic content is not as complete as the data of Cherry and Moray seemed to indicate. Some level of processing of message content in the rejected channel must occur. Otherwise, Treisman's bilingual listener should not have been able to recognize the identity of rejected and shadowed messages, nor should the message in the native tongue of unilingual listeners have been any more difficult to reject than the foreign message. Thus, while it is unclear just how completely message content may be attentionally rejected, it seems certain that the general characteristics of the rejected message are processed and retained. At a descriptive level, this difference in the extent of rejection of general message characteristics and message content might be understood in terms of the amount of monitoring required to extract content verses a general characteristic. This possibility appears worthy of investigation. An extension of these ideas to the problem of target detection in attended and rejected messages is discussed in question 59.

56. Can observers identify a message on the basis of its semantic continuity - if the successive components of the message are presented to different modalities?

On the basis of research by Madsen, Rollins and Senf (1970), it appears that the answer to this question is no. They presented successive components of messages alternately to the visual and auditory modalities. Even though the transitional probabilities of words and phrases was high,

they found that continuity of content was not sufficient to bridge the modality separation.

57. Can an observer shadow a message the successive components of which are rapidly alternated between the two ears?

Treisman (1971) investigated this question. In order to perform this task, attention must be focused on the message and not on the channel. The listener cannot maintain a fixed orientation lateralized to one side. Essentially, listeners have to follow the message back and forth in space. Treisman found that, while listeners were able to perform this task, it was considerably more difficult than shadowing the same message monaurally (also see question 60).

58. If the semantic content is identical in two simultaneously delivered messages, will unilinguals and bilinguals perform differently in a shadowing task?

The importance of this question derives from the importance of semantic continuity in attentional selection. For a unilingual, a message presented in a foreign tongue should convey relatively little semantic information. Hence, if such a message were presented to the rejected channel in a shadowing experiment, where the attended message was in the listener's native tongue, the foreign language message should act effectively the same as a nonsense message and be relatively easy to

select against. In several experiments, Treisman (1964a, b), presented messages in French and English to unilingual and bilingual listeners. An interaural delay time of 3.5 seconds between messages was fixed (see question 46), and both the unilingual and bilinguals were successful in rejecting the French message while shadowing the same message in English at the opposite ear. However, approximately 50% of the bilingual listeners were able to recognize the identity of the two messages. In a second experiment designed to further examine attentional rejection of foreign language messages, Treisman mixed the French and English messages and presented both binaurally. For a unilingual, the addition of the French message into the same channel as the English message should be essentially the same as adding a discontinuous type noise. However, for the bilinguals who could respond to the semantic content of the French message, the situation should be far worse than simply a reduction of signal-to-noise ratio. These expectations were confirmed by Treisman's findings. The bilinguals evidenced greater difficulty in separating the mixed messages.

59. Does semantic contextual information aid in the detection of target signals in unattended (rejected) messages?

This question derives from the finding that semantic content of rejected messages is largely lost in dichotic listening situations (but see question 55). Thus, if semantic contextual information does contribute to detection of target signals embedded in attended messages, and if semantic content is lost due to attentional rejection, then detection performance

for target signals in rejected messages should be worse than detection of signals in attended messages. To test this idea, Treisman and Geffen (1967) used target words which were homophones (e.g., "Right" vs. "Write") such that the detection response (tapping) would depend for accuracy on the processing of contextual information. Incidentally, a detection response was required in addition to the shadowing response. It was found that contextual cues were used by listeners only in the attended message. Correct detection performance was 87% for target signals in attended messages and only 8% for those in the rejected message.

In a follow-up study, Treisman and Riley (1969) used messages consisting of spoken digits and letters where the letters served as the signals to be detected. In this experiment the only response to the target signals that was required was to "stop shadowing." Target signals were presented with equal likelihoods in each message. It was found that correct detection performance was 76% in the attended message and only 33% in the unattended message. While these results are in the same direction as the earlier data, they seem to suggest that less attentional selectivity was present under these conditions, probably due to less available contextual information within the digit-type messages. Thus, it would appear that semantic contextual information can aid in the detection of target signals in attended messages, but not in unattended messages.

60. If two different messages are simultaneously presented to the two ears, and if the listener is instructed to attend to one ear regardless of which message is presented at that ear, will the listener follow the message from the correct ear if it is switched to the opposite side?

Based on a study by Treisman (1960), it appears that listeners will switch channels in order to follow a message in which the semantic continuity is high (see question 54). In Treisman's study, listeners were instructed to shadow the message at one ear while ignoring that at the opposite ear. Messages were presented dichotically to the two ears in segments such that successive segments of each message were switched from one ear to the other. Thus, in order for a listener to continuously shadow a particular message, it was necessary to switch attention from the initially shadowed channel to the rejected channel. Treisman found that, while listeners would switch channels, they would do so only for a few words of the message before switching back to the initially shadowed channel. This switch occurred without listener awareness. Apparently, the selection of channel was stronger than selection for semantic content (also see questions 57 and 61).

61. Can human observers extract messages from simultaneous inputs to two channels if message components are divided between channels and interspersed with irrelevant information?

A number of studies have been concerned with this question (Gray and Wedderburn, 1960; Bartz, Satz, and Fennel, 1967; Broadbent and Gregory,

1964; Yntema and Trask, 1963). In such studies the message might be a word, the syllables of which are divided between channels, or a word phrase where the words are successfully alternated across channels. Typically, within each channel message components are interspersed with irrelevant items, such as digits. The occurrence of an irrelevant item at one ear is paired with the occurrence of a relevant item at the other ear. Generally, it has been found that listeners can perform this task successfully. Obviously, in order for listeners to do so, they must follow the successful components of the message through auditory space from one ear to the other rather than attending only to one ear. In a similar study by Treisman (1960), it was found that listeners follow successive segments of messages from one ear to the other but that this channel switch is only temporary. After only a few words, listeners switch back to the originally shadowed ear (see questions 57 and 60). Probably Treisman's results would have been closer to those of other investigators if listeners had been instructed to follow the successive components of the message from ear to ear. In general, it appears that the evidence indicates that listeners can follow the semantic content of a message across channels if they are instructed to do so. If they are not, it appears that channel selection will preempt selection of message content.

62. Are meaningless messages more easily rejected than meaningful ones?

It appears that, in a dichotic listening situation, the message in the rejected channel will be more distracting if it is meaningful to the

listener than if it is not. For example, Treisman (1964a, b) found that bilinguals had more difficulty rejecting a message in a foreign language than did unilinguals. Likewise, a message in a technical jargon not understood by the listener can be easily rejected (see question 58).

63. If the semantic content of a message is blocked by shadowing a second message, will the blocked message be recognized after termination of shadowing?

Moray (1959) found that no recognition of the rejected message occurs if the recognition test is delayed by as much as 30 seconds after termination of the message (see question 74). However, the relationship of recognition to delay time has not been systematically investigated.

64. If the human observer receives two simultaneous messages in separate channels, will storage in memory of the message to which attention is directed be different than that for the unattended message?

The findings of Bryden (1971) indicate that the answer to this question is yes. It was found that the overall recall of items composing the attended message was greater than that for the unattended message, and the serial position curve for the attended message was nearly flat. The serial position curve for the unattended items showed a distinct recency effect (see question 63).

65. Can human observers recall cross-channel pairs of items presented simultaneously in two channels?

It appears that listeners can recall pairs of items presented simultaneously to the two ears (also see question 26), but they tend to make more errors than they do when they are permitted to group items by channel (ear) and then report the groups (Broadbent and Gregory, 1961, 1965; Madsen, Rollins, and Senf, 1970). Rate of item presentation seems to be a factor in determining whether pair-wise recall will be subject to error, i.e., rates greater than about one pair per second result in increased errors. Pair-wise recall has also been found to result in a loss of order information (Bryden, 1962, 1964; Moray and Barnett, 1965). Although pair-wise recall is always difficult, prolonged practice tends to result in some improvement (Moray and Jordan, 1966). In a further investigation of pair-wise recall, Savin (1967) compared pair-wise recall with sequential recall. Simultaneous pairs of items were presented successively in the same voice and channel. It was found that listeners recalled sequentially presented items rather than paired items (see question 66).

66. What effect does rate of presentation have on recall of two brief itemized messages presented simultaneously in different channels?

Recalled items are grouped by channel and reported first for one channel and then for the second channel, providing the presentation rate of items (digits) exceeds one pair/second (Broadbent and Gregory, 1961, 1965;

Madsen, Rollins, and Senf, 1970). If the presentation rate is less than one pair/second, recalled items tend to be grouped by pairs. A pair, in this case, is one digit/channel presented simultaneously. Provided the presentation rate is great enough, successive (within-channel) items tend to be grouped in recall, not simultaneous (cross-channel) items (Savin, 1967).

67. Does the task of recognizing components of simultaneously presented dichotic messages require less attentional effort than recall of such components?

According to Kahneman (1973), the answer to this question is yes. Kahneman based his opinion on the finding that tests for recall and recognition of members of dichotic pairs yielded different correlation coefficients. In both cases, the correlation coefficients were negative indicating that either recall or recognition of one member of a dichotic pair is associated with failure to recall or recognize the other member. However, the coefficient for recognition was less than that for recall. Since large negative correlation coefficients are indicative of a high level of attentional selectivity (a high degree of rejection of one member of the pair), and since Kahneman assumed that a higher degree of attentional focusing requires more effort, he concluded that recognition requires less attentional effort than recall (see question 38).

## 68. Can precuing reduce the interference between simultaneous judgement tasks?

Precuing refers to the attention-getting action of a signal that precedes a message with which it has been associated. By preceding a message with an attention-getting cue, attentional selection of the appropriate message is rendered more effective, especially if more than one message is present at the same time (see questions 49 and 50). For example, if simultaneous dichotic messages are presented to a listener who must make separate responses to each message, interference will occur and response error rates will be high. However, if each channel or each message has associated with it a distinctive cue, presentation of this cue prior to the message enables the listener to select the proper channel or message and, thus, to respond appropriately (Lindsay, Taylor, and Forbes, 1968). Incidentally, precues may be presented either within the same modality as the message, or in a different modality.

## 69. Is precuing as effective in directing attention to brief auditory messages as it is for messages of longer duration?

Apparently the time required to focus attention by means of a precuing signal is too long for this technique to aid in detection of very brief messages for which selectivity is generally poor without extensive practice. In an experiment by Brown (1970), listeners instructed to attend to one ear did not recognize the correct members of brief dichotically presented word pairs with any greater facility than they did without designation of the correct ear. In this case, precuing of the

correct channel was by means of instructions. By contrast, precuing of longer messages has been shown to improve performance (Broadbent, 1952; Spieth, Curtis, and Webster, 1954).

It is probably incorrect to conclude that precuing is effective only for longer signals. In the area of psychoacoustics, for example, it is standard practice to precue the arrival times of very brief auditory signals since time uncertainty results in considerably poorer performance. Other dimensions of the signal may also be cued, i.e., frequency, intensity, etc. (Swets, 1963). Hence, it seems likely that Brown's failure to obtain any positive effect of precuing on brief messages was due to the fact that it was not the messages that were cued, but rather the channel. Apparently, Brown's brief messages required more specific cuing than just the channel in which they were to occur. In addition to more specific cuing, more extensive practice might also have contributed to the effectiveness of cue-stimulated message selection.

70. Does precuing the presentation of target signals reduce reaction times to single stimulus presentations by more or less than reaction times to dichotically paired presentations?

There appears to be no difference. Treisman (1970), and Treisman and Fearnley (1971), found that the reduction of reaction times to target signals by precuing was essentially the same for single and dichotically paired presentations of stimuli. The average reduction in reaction time in each case was approximately 115 msec.

71. What is the effect of post-stimulus cuing on retrieval of auditory information?

Interestingly enough, presentation of a cue signal immediately after offset of an auditory message serves to increase memory for message contents. Moray et al. (1965), found that recall for messages followed by a cue was better than recall for messages not followed by a cue. It may be that Moray's post-stimulus cuing effect is essentially the same as the "suffix effect" reported by Crowder and Morton (1969) and others. Error rates in recall were found to be influenced by the sound that terminated message presentations (also see questions 3, 17, and 92).

72. If an observer attends to (shadows) one of two continuous dichotic messages, and if target signals occur in both messages with equal likelihood, to what extent will the detection of target signals in the unattended message be reduced relative to the detection of target signals in the attended message?

Detectability of simultaneous targets at the two ears has been studied by means of both the monitoring technique and the shadowing technique. In both cases, target signals are present simultaneously at the two ears within the context of different ongoing messages. Treisman and Geffen (1967), and Treisman and Riley (1969), employed the shadowing technique, while Moray (1970a, b), and Moray and O'Brien (1967), utilized the monitoring technique in which they required an immediate overt response to each target signal. Kahneman et al. (described in Kahneman, 1973), also

utilized the monitoring technique, but did not require an immediate overt response. They manipulated the amount of effort required for recognition responses.

In all of the above studies, negative correlations were found between pairs of target items, i.e., if one member of a pair was correctly detected or recognized, then the other pair member would have a low probability of detection or recognition. Also, the probability that the pair member located in the attended message would be detected or recognized was always higher than that for the pair member located in the unattended message (also see questions 49 through 52). The differences in these probabilities was greatest in the shadowing experiments and the monitoring experiment of Moray which required an immediate overt response. According to Kahneman (1973), this was due to the larger amount of effort demanded by these tasks. His utilization of the monitoring technique required less effort and, consequently, the size of the negative correlations he obtained were smaller. This indicated that if the attentional effort demanded by the tasks could be reduced, the recognizability of two simultaneous targets would be increased.

73. Will the detection of target signals embedded in a continuously monitored message at one ear be corrupted by introduction of an irrelevant message at the other ear?

It does not appear that the detectability of target signals within a message that is monitored in one channel will be seriously affected by

irrelevant material introduced in the opposite channel. Several studies in which this was examined (Moray and O'Brien, 1967; Underwood and Moray, 1972) found that the detection of occasional target signals was not affected to any significant extent by the presence of irrelevant material at the unattended ear. Their target signals were digits embedded in lists of letters. Performance was about the same with, or without, the irrelevant message present at the unattended ear.

74. Will recognition-memory for items contained within a continuously monitored message at one ear be deteriorated by introduction of an irrelevant message at the other ear?

Research conducted by Kahneman et al. (1973), indicates that the introduction of an irrelevant message at the opposite ear has relatively little effect on recognition memory for a continuously monitored message (also see question 32). They obtained a decrement of only 7% (from 61% to 54%) in the recognition of relevant items under the two conditions of exposure -- relevant message only, and relevant plus irrelevant message. In both conditions there occurred a 32% false recognition rate for unpresented items. Of the irrelevant items, 37% were judged to be familiar. Hence, recognition performance is altered relatively little by introduction of irrelevant material at the opposite ear. By contrast, Moray (1959) found that listeners who shadowed a message on one ear later failed to recognize a phrase that had been repeated in the presentation to the opposite ear (see question 63). Apparently, memory for unattended messages is far worse than memory for attended messages.

75. Will speed of reaction to target signals embedded in a continuously monitored message at one ear be impaired by introduction of an irrelevant message at the other ear?

In a study by Ninio and Kahneman (described in Kahneman, 1973) reaction times of listeners to target signals (animal names) inserted in among other words was as fast with the irrelevant message at the other ear as without it (also see questions 49 through 52 and question 78).

76. Can observers detect simultaneous, dichotic presentations of two different target signals?

Generally, the detection of simultaneous presentations of two different target signals, one at each ear, has been found to be poor (see questions 25 through 28). In a study by Moray and O'Brien (1967), messages consisting of 90% digits and 10% letters were presented dichotically at a rate of 100 items/minute and letter targets were inserted into each string of digits. Listeners indicated the detection of a signal at the left ear, or right ear by means of left hand or right hand key presses respectively. It was found that both responses occurred on only 17% of the simultaneous target presentations. On 99% of these presentations, at least one signal was responded to. In later studies by Moray (1970a, b), messages consisted of dichotic tone series and targets were transient increments in loudness. Again, it found that listeners were likely to respond to one of the concurrent targets, but not to both.

A variation on the above procedure for studying the detectability of dichotic target signals was employed by Shaffer and Hardwick (1969b). They presented dichotic word messages in which the target was a successive repetition of a word in either channel. In this case, the dichotic targets were not simultaneous. They found that 60% of all targets presented were detected, hence there was some processing in both channels. They also found a sequential dependence such that, if the listener detected a target in one channel, he was likely to detect the next one in that channel, but unlikely to detect the next target in the opposite channel.

The results of all these studies are consistent with the generalization that simultaneous processing of dichotic information is far worse than either monaural processing of single inputs or binaural processing of highly correlated inputs, where the latter may be just slightly better than the processing of dichotic inputs, only one of which is selectively attended.

77. Can observers detect asynchronous dichotic target signals better than synchronous (simultaneous) signals?

Clearly, the answer to this question is yes. Research by Treisman (1972), Treisman and Davies (1972), and Avner (described in Kahneman, 1973), as well as others, indicates that the detectability of asynchronous dichotic target signal falls somewhere between detectability of targets at one ear

only and the detectability of simultaneous dichotic targets, where the latter yields the poorest performance.

78. Are reaction times of observers detecting target signals faster in the case of single stimulus presentations than in the case of dichotically paired presentations?

It appears that reaction times to pairs of dichotic stimuli are slower than reaction times to single stimulus presentations (also see question 75). Treisman (1970), and Treisman and Fearnley (1971), presented signals (spoken digits) either singly or as one member of a dichotic pair, where the other member was a non-signal (a spoken nonsense syllable). It was found that reaction times to pairs was longer by about 80 msec.

79. Can observers detect target signals contained within paired dichotic presentations as proficiently with attention divided between channels as they can with attention focused on one channel?

In a study by Ninio and Kahneman (described in Kahneman, 1973) it was found that listeners detected 77% of the targets (animal names), even though the rate of presentation was fast (two words pairs/second).

80. Are reaction times of observers detecting target signals contained within paired dichotic presentations faster if attention is focused on one channel, or divided between both channels?

Again, on the study by Ninio and Kahneman (described in Kahneman, 1973) it was found that reaction times averaged 140 msec for the focused attention condition. This was a consistent, although not large, difference.

81. Can observers who are shadowing a continuous auditory message at one ear detect a target signal presented either to the other ear or visually?

The answer to this question has been found to be yes, but it should be noted that the target signal was introduced into a noise-free channel. That is, the message to which attention was directed in studies of this question was located at one ear while the target signal was introduced into the opposite, silent, ear. Target signals in this technique were thus very distinctive and listeners detected their occurrence with a high degree of accuracy.

However, detection of signals in the unattended channel has been shown to be disruptive of shadowing performance for attended messages. This effect was shown by both Mowbray (1964) and by Treisman and Geffen (1968).

Mowbray found that the detection of a single significant target word at the unattended ear was sufficient to disrupt shadowing. Likewise, Treisman and Geffen showed that, in the case of a target signal contained in a continuous auditory message presented to the unattended ear,

detection of the signal interfered with shadowing in the sense that the word coinciding with the signal was frequently missed. Furthermore, Mowbray (1962) demonstrated that detection of a visual target also disrupted auditory shadowing (also see question 26). Thus, it appears that even though the attentional rejection of inputs other than the attended message is very marked in shadowing tasks, the occurrence of signals in noise-free channels (or highly distinctive signals in noisy channels) effectively cuts through the attentional block (see questions 49 through 52).

82. If a light flash and a tone are signals for different responses, which signal will command a response if both are presented to the observer simultaneously?

The findings of Colavita (described in Kahneman, 1973) indicate that paired presentations of light and tone signals, each of which calls for a different response, do not lead to two immediate responses even though both are physically possible. Instead, on 49 out of 50 simultaneous presentations of lights and tones, the responses to the light flash occurred. On 17 of these presentations, the observers were unaware that the tone had been presented.

83. Can human observers attend to both an auditory message and a visual message when the two messages are presented simultaneously?

Contrary to popular opinion, it appears that the answer to this question is no. Based on findings by Mowbray (1953) observers cannot listen to one story while reading another. It was found that comprehension of the listened-to story was near chance performance. In a further study, Mowbray (1954) found that simultaneously presented visual and auditory messages could not be used by observers in the performance of a complex task. Not only could observers not use the simultaneous messages, they usually denied noticing the simultaneity.

84. Is auditory recognition disrupted by the simultaneous processing of visual information?

The answer to this question is yes. Massaro and Kahn (1973) found that identification of light duration simultaneously with tone identification resulted in a performance decrement relative to the situation in which the tone alone was identified. In a further study by Massaro and Warner (1965; described in Massaro, 1977), observers were required to selectively attend to a visual input, an auditory input, or to both, and assign the input (or inputs) to the appropriate category (two categories for each input). A backward recognition masking paradigm was used. As the signal-masker interval increased, performance improved in all three conditions. However, performance in the two selective attention conditions improved more rapidly than in the divided attention condition.

85. Can observers monitor two messages presented simultaneously in the same modality as well as they can monitor two messages presented in different modalities?

According to the findings of Treisman and Davies (1972), the answer to this question is no. Observers' ability to monitor two messages simultaneously present in the same modality was found to be poor, a finding consistent with numerous other studies on divided attention (see question 25). Treisman and Davies found that even if concurrent messages were delivered via different modalities, divided attention performance was worse than focused attention performance.

86. Is interference with memory more likely to arise between inputs to the same modality than between inputs to different modalities?

Several studies have indicated that the answer to this question is yes. Parkinson (1972) found that recall for multiple inputs to the same modality (either vision or audition) was worse than recall of the same items separately introduced into different modalities. Also, in a bisensory split-span experiment, Treisman and Davies (1972) found that the usual memory loss for the second series was avoided if that series was presented on a different modality, and if different modes of response were employed for the series. This suggests that at least some of the interference is attributable to the task required of the observer.

87. Can auditory inputs interfere with the processing of simultaneously presented visual inputs?

Several studies by Greenwald (1970a, b, and c) indicate that the answer to this question is yes. In the case of simultaneously presented visual and auditory digits, reaction times for reading visual digits were found to be slower when they were different than the auditory digits. Also, interference from the auditory input was found to be greater when listeners had to say the visual digit than when they had to write it. This is indicative of an interaction between modality of the interfering stimulus and the modality of the response.

88. Will the information delivered in a target signal be remembered better if the signal is introduced into an auditory message being shadowed, or presented visually?

It appears that single target words are retained better if they are presented visually than if they are included within the auditory message (Kroll et al., 1970). Apparently, retroactive interference from the shadowing task does not affect retention of visual information. Perhaps, visual and auditory storage are, to some extent, independent.

89. Will recall of the information content of long messages (several sentences) be better if the information is presented in the auditory or visual modality?

The evidence appears to indicate that retention will be better if the information is presented in the auditory modality. Levy (1975) found that auditory input of three sentences resulted in better recall than visual input of the same sentences. However, this modality effect appeared only on recall of the last of the three sentences. The effect of simultaneous articulation (counting from one to ten during sentence presentation) interfered with recall of all three sentences. This suggests that the superior auditory recall was due to some form of articulatory rehearsal.

90. If sequential items of information must be recalled, will retention be better if the items are presented visually or auditorily?

Again, retention is better for auditory presentation. The superior retention of auditorily, as opposed to visually, presented items (e.g., words) is well established empirically (Nilsson, Ohlsson, and Ronnberg, 1977). This effect is referred to as the "modality effect" in verbal memory research. It has been shown to occur in various short-term memory tasks, e.g., paired associates, free recall, probed recall, serial recall, and recognition (e.g., see Craik, 1969; Watkins, 1972; Scarborough, 1972; Nilsson, 1973; Murdock, 1969; Hopkins et al., 1971). It should be pointed out that the effect is sensitive to the mode of information presentation, i.e., whether the items are presented to one modality at a time--single

mode presentation--or to both modalities in a random order--mixed mode presentation. In the single mode case, auditory superiority is evident only in the recency part of the serial position curve. In the mixed mode case, auditory superiority is evident at all serial positions. The origin of the modality effect is uncertain (Watkins, Watkins and Crowder, 1974).

91. Is sequential memory for informational items in series affected by the phonological similarity of the items?

The answer to this question is yes. Errors of substitution in recall (wrong letter substituted for correct letter) are greater if phonological similarity of items is high. The "confusion effect" (Conrad, 1964), intrusions of phonologically similar items, presumably occurs whether the items are learned from visual or auditory inputs. Related findings have also been reported by Conrad and Hull (1964). These studies were done with visual lists of letters where phonological similarity was the variable. However, this detrimental effect of phonological similarity appears to be limited to the retention of order information, i.e., recall of a list of items in a particular order. If the subjects are permitted "free recall" rather than "serial recall," phonological similarity has been found to enhance performance (Watkins, Watkins and Crowder, 1974). In fact, Healy (1975) demonstrated that the phonological similarity effect is limited to temporal order and not spatial order. However, Crowder (1978) has shown that some retention does occur in temporal order even for phonologically identical items. In a different procedure, Crowder and Cheng (1973) found that the detrimental influence of a phonologically

similar suffix at the end of a series of sounds to be recalled serially was greater than that produced by a dissimilar suffix. Related similarity effects have been found by Wickelgren (1965a, b, and c), Baddely (1966a, b), Bruce and Murdock (1968), Bruce and Crowley (1970), Parkinson, Parks, and Kroll (1971), as well as others.

92. Is auditory memory for a series of spoken sounds affected by the sound that terminates the series?

The answer to this question is yes. This is called the "suffix effect" (also see question 71). If a series of spoken sounds--whether characters or words--is consistently followed by a terminator sound (suffix) each time the series is heard, error rates in recall will depend on the nature of the suffix (Crowder and Morton, 1969; Roediger and Crowder, 1976). Nonverbal suffixes (buzzers, tones, etc.) were found to exert relatively little influence on serial recall as compared with verbal suffixes which increase the error rate. However, use of two, or three, verbal suffixes reduces the error rate somewhat as compared with that obtained with only one verbal suffix (Morton, 1976; Crowder, 1978). Also, if the suffix is phonologically similar to the sounds to be recalled, its detrimental effects are greater (Crowder and Cheng, 1973). Further, if the suffix is structurally similar to the sounds to be recalled (consonate-vowel versus vowel sounds versus buzzer), its detrimental effects are greater (Crowder, 1978).

93. Will recognition of the duration of a target tone embedded in a series of discrete tones of fixed or alternating frequency be affected by the rate of tone presentation?

Massaro (1976) found that the answer to this question is yes. He presented 20 msec tones binaurally at rates that ranged between 20 and 3.5 tones per second. The tones were either presented at the same frequency or alternated between 440 Hz and 988 Hz. The target tone was either "longer than" or "shorter than" the other tones in a series. It was found that recognition improved with decreasing rates of presentation. Performance reached slightly higher levels for sequences of tones of the same frequency. These findings indicate that backward recognition masking may operate at high rates of tone presentation and that a tonal series consisting of fixed duration components may serve as a duration standard against which increases or decreases may be recognized (also see questions 11, 12, and 17).

94. Is proficiency in counting the number of tones in a series influenced by the rate of presentation of the tones?

The work of several researchers indicates that the answer to this question is yes. In an experiment involving sequences of five, six, seven, or eight 20 msec tones (800 Hz), Massaro (1976) found that counting accuracy improved from approximately 40% at a rate of about 20 tones per second to nearly 100% at a rate of about 3.5 per second. Counting performance improved at a faster rate if the tones were presented monaurally than if

they were switched between the ears. Presumably, the backward recognition masking that seems to occur at fast rates of presentation interferes with the identification of individual tones that is necessary for counting. The decrement in counting proficiency obtained under the alternating ear condition suggests that series of tones located at different points in auditory space are difficult to integrate into a countable sequence. This is consistent with findings from Harvey and Treisman (1973).

APPENDIX I.

LIST OF QUESTIONS WITH REFERENCES

1. Can listeners identify categories of nonspeech sounds?

(Miller, Weir, Pastore, Kelley & Dooling, 1976; Pisoni, 1977; Locke & Kellar, 1973; Pastore, 1976; Cutting, 1977, 1978; Cutting & Rosner, 1974, 1976; Studdert-Kennedy, Liberman, Harris & Cooper, 1970; Mattingly, Liberman, Syrdal & Halwes, 1971; Kuhl & Miller, 1975; Morse & Snowden, 1975; Sinnot, Beecher, Moody, & Stebbins, 1976; Waters & Wilson, 1976.)

2. Must categorical identification of sounds be learned, or is this innate?

(Fletcher, 1940; Zwicker et al., 1957; Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Jusczyk, Rosner, Cutting, Foard, & Smith, 1977; Plomp & Bouman, 1959; Plomp & Levelt, 1965; Mulligan et al., 1967; Mulligan et al., 1968; Mulligan & Elrod, 1970; Patterson, 1971, 1974, 1976.)

3. Does memory for auditory inputs exist at an initial, sensory ("precategorical") level, or is it limited to the more abstract, highly processed ("postcategorical") levels of short-term and long-term storage?

(Holding, 1975; Crowder, 1978; Huggins, 1975; Kubovy & Howard, 1976; Deutsch, 1975a, 1978; Deutsch & Feroe, 1975.)

4. Is memory better for absolute values of acoustic inputs than it is for relationships among input values?

(Deutsch, 1969, 1978, 1973, 1970, 1975a, 1975b, 1972b; Attneave & Olson, 1971, Pollack, 1972, 1964; Ward, 1970.)

5. What global cues for recognition and memory are available in complex tonal sequences?

(Deutsch, 1972a, 1978; White, 1960; Dowling & Fujitani, 1971.)

6. What factors contribute to the formation of perceptual configurations of sounds?

(Bregman & Campbell, 1971; Miller & Heise, 1950; Heise & Miller, 1951; Van Noorden, 1975; Deutsch, 1978; Divenyi & Hirsh, 1974, 1975; Fraisse, 1978; Perkins, 1974; Handel, 1973, 1974; Restle, 1972; Warren & Obusek, 1972; Garner, 1974; Martin, 1972.)

7. If a repeating, rapid sequence of discrete tones is presented monaurally to a listener, what characteristics of these tones will determine the perceptual grouping of tonal components that is necessary for pattern (order and temporal spacing) recognition?  
  
(Bregman & Dannenbring, 1973, 1977; Bregman & Campbell, 1971; Dannenbring & Bregman, 1976; Bregman, 1978a; Bregman, 1978b; Van Noorden, 1975; Bregman & Rudnick, 1975; Bregman & Pinker, 1978.)
8. What are the structural components from which auditory patterns are formed?  
  
(Deutsch, 1978; Bregman, 1978a; Jones, 1974, 1978.)
9. What physical dimensions of tonal inputs influence pitch perception?  
  
(Stevens, Volkman, & Newman, 1937; Stevens & Volkman, 1940; Doughty & Garner, 1948; Cohen, 1961; Small & Campbell, 1961; Ward, 1970.)
10. What basic features of tones are responsible for recognition of pitch combinations?  
  
(Bachem, 1954; Humphreys, 1919; Blackwell & Schlosberg, 1943; Ward, 1954; Attneave & Olson, 1971; Deutsch, 1969, 1978; Plomp, Wagenaar, Mimsen, 1973; Deutsch & Roll, 1974; Burns & Ward, 1973; Siegel & Sopo, 1975.)
11. Is recognition of the pitch category ("high" or "low") assigned to tones affected by the temporal proximity of other sounds?  
  
(Massaro, 1972; Hawkins & Presson, 1977; Massaro, Cohen, & Idson, 1976; Massaro, 1975.)
12. Will recognition of the pitch of a target tone embedded in a series of tones of constant pitch be affected by the rate of tone presentation?  
  
(Massaro, 1976.)
13. Under what conditions may pitch shifts occur?  
  
(Christman & Williams, 1963; Mulligan & Adams, 1968; Ward, 1963; Egan & Meyer, 1950; Webster & Schubert, 1954; Webster, Miller, Thompson, & Davenport, 1952; Ward, 1970.)
14. How can the illusion of an endlessly increased pitch be created with a limited number of tones?  
  
(Shepard, 1964.)

15. Do attentional shifts alter pitch and loudness difference thresholds?  
(Ingham, 1957; Moray, 1970a, b; Herman, 1965.)
16. What physical dimensions of sounds influence loudness perception?  
(Stevens, 1936, 1966; Stevens & Davis, 1938; Stevens & Guirao, 1967; Fletcher, 1940; Fletcher & Munson, 1933; Sivian & White, 1933; Reynolds & Stevens, 1960; Hellman & Zwislocki, 1963, 1964; Scharf & Fishken, 1970; Swicker & Scharf, 1965; Richards, 1968; Levelt, Riemersma, & Bunt, 1972; Marks, 1974, 1979; Port, 1963; Zwicker & Feldtkeller, 1955; Mulligan et al., 1982.)
17. Is recognition of the loudness and sound quality of tones influenced by the temporal proximity of other sounds?  
(Moore & Massaro, 1973.)
18. Given a complex mixture of acoustic inputs, can listeners selectively attend to one message, component, etc., contained within the complex?  
(Cherry, 1957; Helmholtz, 1954.)
19. What factors increase the probability that an observer will respond selectively to one message presented simultaneously in a complex of other messages?  
(Broadbent, 1958.)
20. Is response set an effective mechanism for isolating relevant information contained within concurrent competing signals?  
(Moray & O'Brien, 1967.)
21. If a listener has no prior set to respond selectively to either one of two messages, what will determine which message will be selected, if either?  
(Tolhurst & Peters, 1956; Moray, 1970c.)
22. Is the detection of signals in noise any better if the observer has prior information about the physical characteristics of the signals?  
(Swets, 1963.)

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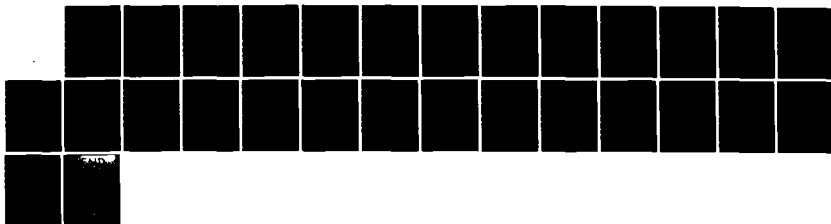
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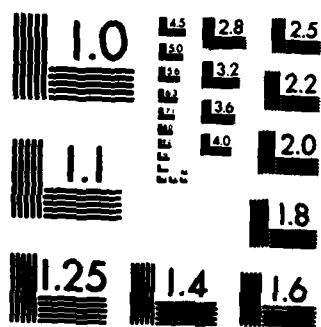
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23. Do observers experience more difficulty in identifying or in tracking relevant messages?

(Broadbent, 1952.)

24. Given inputs to two modalities, or to two channels within the same modality, can human observers accurately identify simultaneous events contained in the two inputs?

(Sternberg & Knoll, 1972.)

25. Can two simultaneously ongoing messages be processed at the same time by human observers?

(Broadbent, 1952, 1954; Mowbray, 1953, 1954; Poulton, 1953; Spieth, Curtis, and Webster, 1954; Webster & Thompson, 1954; Webster & Solomon, 1955.)

26. Can human observers recall two, brief messages presented simultaneously in different modalities or channels?

(Broadbent, 1954.)

27. Is recognition-memory for information presented simultaneously in two channels (dichotically) as good as recognition-memory for information presented in one channel?

(Levy, 1971.)

28. Can observers identify (label) different stimuli presented simultaneously as well as they can identify the same stimuli presented one at a time?

(Lindsay, Cuddy, & Tulving, 1965; Tulving & Lindsay, 1967; Lindsay, Taylor, & Forbes, 1968.)

29. Can listeners respond appropriately to long messages while, at the same time, receiving them?

(Moray, 1970c.)

30. What two tasks have been utilized most often in studies of auditory attention?

(Kahneman, 1973.)

31. Who performed the original studies employing the "speech shadowing" technique?  
(Cherry, 1953; Poulton, 1953.)
32. Given two auditory messages, one of which is to be shadowed and the other ignored, how effective is the observer's performance? That is, how effective is attentional selection and rejection as evaluated in shadowing performance?  
(Cherry, 1953; Cherry & Taylor, 1954; Lawson, 1966; Treisman & Riley, 1969.)
33. How resistant to intrusions is the attentional rejection of one message due to shadowing of another message? How complete is the attentional rejection?  
(Moray, 1959; Moray & Taylor, 1958; Miller & Selfridge, 1950; Taylor & Moray, 1960; Moray, 1966; Moray & Barnett, 1965; Moray, 1970a; Treisman, 1965; Harrison, Moray, & Treisman, 1970.)
34. What characteristics of auditory messages can serve as a basis for attentional selection if concurrent messages are presented monaurally? Binaurally?  
(Egan, Carterette, & Thwing, 1954; Spieth, Curtis, & Webster, 1954; Broadbent, 1952; Cherry, 1953; Broadbent, 1958; Tolhurst & Peters, 1956.)
35. Under what conditions will listeners switch attention from the shadowed message to the rejected message?  
(Moray, 1959, 1966, 1970a; Miller & Selfridge, 1950; Moray & Taylor, 1958; Taylor & Moray, 1960; Moray & Barnett, 1965; Treisman, 1965; Harrison, Moray, & Treisman, 1970.)
36. If one of two simultaneously presented dichotic messages is shadowed, will attention shift to the rejected message if it is made more intense than the one that is shadowed?  
(Moray, 1958.)
37. Does ear dominance influence the selection of one of two simultaneously presented dichotic target signals?  
(Kahneman, 1973.)

38. Can listeners rapidly switch attention from the input at one ear to the input at the other?  
(Gopher & Kahneman, 1971; Kahneman, 1973.)
39. By what means does a listener select one voice from a complex of voices speaking at the same time?  
(Cherry & Sayers, 1956; Egan, Carterette, & Thwing, 1954.)
40. If more than one concurrent message requires a differential response, will separation of the messages in "auditory space" facilitate performance?  
(Broadbent, 1958.)
41. What distinguishing characteristic of auditory signals is most effective in facilitating selective listening under multi-signal conditions?  
(Poulton, 1953; Spieth, Curtis, & Webster, 1954; Treisman, 1965b.)
42. If two or more simultaneous auditory signals originate from the same point in space, or are presented at the same ear, what physical cues are available to permit attentive selection of one signal from among the complex?  
(Treisman, 1964b; Treisman, 1964a.)
43. Do localization cues contribute to temporal resolution of rapid sequential signals?  
(Axelrod & Guzy, 1968; Axelrod, Guzy, & Diamond, 1968; Axelrod & Powazek, 1972.)
44. Can listeners reject two messages while shadowing a third message?  
(Treisman, 1961, 1964a, b.)
45. Does the temporal continuity of irrelevant messages contribute to the effectiveness of selective attention?  
(Kahneman, 1973.)

46. If listeners shadow one of two identical messages presented at the two ears, one of which is delayed relative to the other by a time difference  $\tau$ , at what value of  $\tau$  will the two function as different messages?

(Cherry, 1953; Treisman, 1961, 1964c; Moray, 1960.)

47. Can auditory messages be better resolved if presented to the same ear receiving noise or if presented to the contralateral ear?

(Treisman, 1961, 1964b.)

48. Can observers monitor information presented in one channel without intrusion of irrelevant information from a second channel if they expect important signals to be delivered in the second channel?

(Kahneman, 1973.)

49. Will a listener who is shadowing a message presented at one ear be more likely to notice a message at the other ear if it is preceded by the listener's name?

(Moray, 1959.)

50. Will stress-associated signals contained in a rejected message affect a listener's ability to shadow a second message simultaneously present at the contralateral ear?

(Corteen & Wood, 1972.)

51. Does physical distinctiveness aid in the detection of target signals in unattended (rejected) messages?

(Treisman & Riley, 1969; Lawson, 1966.)

52. Will distinctive target signals more effectively block competing messages than non-distinctive targets?

(Kahneman, 1973.)

53. Does temporal priority among messages contribute to message selection?

(Broadbent, 1955, 1958; Spieth, Curtis, & Webster, 1954; Poulton, 1956; Moray, 1970a; Schubert & Parker, 1955.)

54. Is attention selective for semantic continuity of auditory messages?

(Treisman, 1960.)

55. Can attention to a message at one ear block reception of semantic continuity of a message delivered simultaneously to the opposite ear without blocking reception of its general characteristics?  
(Cherry, 1953; Moray, 1959.)
56. Can observers identify a message on the basis of its semantic continuity if the successive components of the message are presented to different modalities?  
(Madsen, Rollins, & Senf, 1970.)
57. Can an observer shadow a message the successive components of which are rapidly alternated between the two ears?  
(Treisman, 1971.)
58. If the semantic content is identical in two simultaneously delivered messages, will unilinguals and bilinguals perform differently in a shadowing task?  
(Treisman, 1964a, b.)
59. Does semantic contextual information aid in the detection of target signals in unattended (rejected) messages?  
(Treisman & Geffen, 1967.)
60. If two different messages are simultaneously presented to the two ears, and if the listener is instructed to attend to one ear regardless of which message is presented at that ear, will the listener follow the message from the correct ear if it is switched to the opposite side?  
(Treisman, 1960.)
61. Can human observers extract messages from simultaneous inputs to two channels if message components are divided between channels and interspersed with irrelevant information?  
(Gray & Wedderburn, 1960; Bartz, Satz, & Fennell, 1967; Broadbent & Gregory, 1964; Yntema & Trask, 1963.)
62. Are meaningless messages more easily rejected than meaningful ones?  
(Treisman, 1964a, b.)

63. If the semantic content of a message is blocked by shadowing a second message, will the blocked message be recognized after termination of shadowing?

(Moray, 1959.)

64. If the human observer receives two simultaneous messages in separate channels, will storage in memory of the message to which attention is directed be different than that for the unattended message?

(Bryden, 1971.)

65. Can human observers recall cross-channel pairs of items presented simultaneously in two channels?

(Broadbent & Gregory, 1961, 1965; Madsen, Rollins, & Senf, 1970; Bryden, 1962, 1964; Moray & Barnett, 1965; Moray & Jordan, 1966.)

66. What effect does rate of presentation have on recall of two brief itemized messages presented simultaneously in different channels?

(Broadbent & Gregory, 1961, 1965; Madsen, Rollins, & Senf, 1970.)

67. Does the task of recognizing components of simultaneously presented dichotic messages require less attentional effort than recall of such components?

(Kahneman, 1973.)

68. Can precuing reduce the interference between simultaneous judgement tasks?

(Lindsay, Taylor, & Forbes, 1968.)

69. Is precuing as effective in directing attention to brief auditory messages as it is for messages of longer duration?

(Brown, 1970; Broadbent, 1952; Speith, Curtis, & Webster, 1954.)

70. Does precuing the presentation of target signals reduce reaction times to single stimulus presentations by more or less than reaction times to dichotically paired presentations?

(Treisman, 1970; Treisman & Fearnley, 1971.)

71. What is the effect of post-stimulus cuing on retrieval of auditory information?

(Moray et al., 1965.)

72. If an observer attends to (shadows) one of two continuous dichotic messages, and if target signals occur in both messages with equal likelihood, to what extent will the detection of target signals in the unattended message be reduced relative to the detection of target signals in the attended message?

(Treisman & Geffen, 1967.)

73. Will the detection of target signals embedded in a continuously monitored message at one ear be corrupted by introduction of an irrelevant message at the other ear?

(Moray & O'Brien, 1967; Underwood & Moray, 1972.)

74. Will recognition-memory for items contained within a continuously monitored message at one ear be deteriorated by introduction of an irrelevant message at the other ear?

(Kahneman, 1970; Levy, 1971; Moray, 1959.)

75. Will speed of reaction to target signals embedded in a continuously monitored message at one ear be impaired by introduction of an irrelevant message at the other ear?

(Kahneman, 1973.)

76. Can observers detect simultaneous, dichotic presentations of two different target signals?

(Moray & O'Brien, 1967; Moray, 1970a, b; Shaffer & Hardwick, 1969b.)

77. Can observers detect asynchronous dichotic target signals better than synchronous (simultaneous) signals?

(Treisman, 1972; Treisman & Davies, 1972; Kahneman, 1973.)

78. Are reaction times of observers detecting target signals faster in the case of single stimulus presentations than in the case of dichotically paired presentations?

(Treisman, 1970; Treisman & Fearnley, 1971.)

79. Can observers detect target signals contained within paired dichotic presentations as proficiently with attention divided between channels as they can with attention focused on one channel?

(Kahneman, 1973.)

80. Are reaction times of observers detecting target signals contained within paired dichotic presentations faster if attention is focused on one channel, or divided between both channels?

(Kahneman, 1973.)

81. Can observers who are shadowing a continuous auditory message at one ear detect a target signal presented either to the other ear or visually?

(Treisman & Geffen, 1968.)

82. If a light flash and a tone are signals for different responses, which signal will command a response if both are presented to the observer simultaneously?

(Kahneman, 1973.)

83. Can human observers attend to both an auditory message and a visual message when the two messages are presented simultaneously?

(Mowbray, 1953, 1954.)

84. Is auditory recognition disrupted by the simultaneous processing of visual information?

(Massaro & Kahn, 1973; Massaro & Warner, 1976.)

85. Can observers monitor two messages presented simultaneously in the same modality as well as they can monitor two messages presented in different modalities?

(Treisman & Davies, 1972.)

86. Is interference with memory more likely to arise between inputs to the same modality than between inputs to different modalities?

(Parkinson, 1972; Treisman & Davies, 1972.)

87. Can auditory inputs interfere with the processing of simultaneously presented visual inputs?  
(Greenwald, 1970a, b, and c.)
88. Will the information delivered in a target signal be remembered better if the signal is introduced into an auditory message being shadowed, or presented visually?  
(Kroll et al., 1970.)
89. Will recall of the information content of long messages (several sentences) be better if the information is presented in the auditory or visual modality?  
(Levy, 1975.)
90. If sequential items of information must be recalled, will retention be better if the items are presented visually or auditorily?  
(Nilsson, Ohlsson, & Ronnberg, 1977; Watkins, Watkins, & Crowder, 1974; Craik, 1969; Watkins, 1972; Scarborough, 1972; Nilson, 1973; Murdock, 1969; Hopkins, Edwards, & Gavelek, 1971.)
91. Is sequential memory for informational items in series affected by the phonological similarity of the items?  
(Conrad, 1964; Conrad & Hull, 1964; Watkins, Watkins, & Crowder, 1974; Healy, 1975; Crowder, 1978; Crowder & Cheng, 1973; Wickelgren, 1965a, b, c; Baddely, 1966a, b; Bruce & Murdock, 1968; Bruce & Crowley, 1970; Parkinson, Parks, & Kroll, 1971.)
92. Is auditory memory for a series of spoken sounds affected by the sound that terminates the series?  
(Crowder & Morton, 1969; Roediger & Crowder, 1976; Morton, 1976; Crowder, 1978; Crowder & Cheng, 1973.)
93. Will recognition of the duration of a target tone embedded in a series of discrete tones of fixed or alternating frequency be affected by the rate of tone presentation?  
(Massaro, 1976.)
94. Is proficiency in counting the number of tones in a series influenced by the rate of presentation of the tones?  
(Massaro, 1976; Harvey & Treisman, 1973.)

## APPENDIX II.

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